US006793162B2

(12) **United States Patent**
Dallmeyer et al.

(10) **Patent No.: US 6,793,162 B2**
(45) **Date of Patent: Sep. 21, 2004**

(54) **FUEL INJECTOR AND METHOD OF FORMING A HERMETIC SEAL FOR THE FUEL INJECTOR**

(75) Inventors: **Michael P. Dallmeyer**, Newport News, VA (US); **Robert McFarland**, Newport News, VA (US); **Michael J. Hornby**, Williamsburg, VA (US); **James Robert Parish**, Yorktown, VA (US); **Dennis Bulgatz**, Williamsburg, VA (US); **Ross Wood**, Yorktown, VA (US); **Bryan Hall**, Newport News, VA (US)

(73) Assignee: **Siemens Automotive Corporation**, Auburn Hills, MI (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **10/246,483**

(22) Filed: **Sep. 19, 2002**

(65) **Prior Publication Data**

US 2003/0019958 A1 Jan. 30, 2003

Related U.S. Application Data

(63) Continuation of application No. 09/828,487, filed on Apr. 9, 2001, now Pat. No. 6,676,044.

(60) Provisional application No. 60/195,187, filed on Apr. 7, 2000, provisional application No. 60/200,106, filed on Apr. 27, 2000, and provisional application No. 60/223,981, filed on Aug. 9, 2000.

(51) **Int. Cl.**[7] **B05B 1/30**; F02M 51/00

(52) **U.S. Cl.** **239/585.1**; 239/585.3; 239/585.5; 239/533.3; 239/88

(58) **Field of Search** 239/88, 5, 89, 239/91, 596, 533.2, 533.3, 533.9, 533.11, 533.14, 585.1, 585.2, 585.3, 585.4, 585.5, 587.3, 900, 590; 251/129.15, 129.21, 127

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,567,135 A	3/1971	Gebert	....	239/585
4,342,427 A	8/1982	Gray	....	239/585
4,520,962 A	6/1985	Momono et al.	....	239/585
4,552,312 A	11/1985	Ohno et al.	....	239/585
4,597,558 A	7/1986	Hafner et al.	....	251/129.15

(List continued on next page.)

FOREIGN PATENT DOCUMENTS

DE	43 29 976	3/1995
DE	100 25 331	12/2000
EP	1 219 816	7/2002
EP	1 219 825	7/2002
WO	WO 95/16126	6/1995
WO	WO 98/05861	2/1998
WO	WO 00/43666	7/2000

OTHER PUBLICATIONS

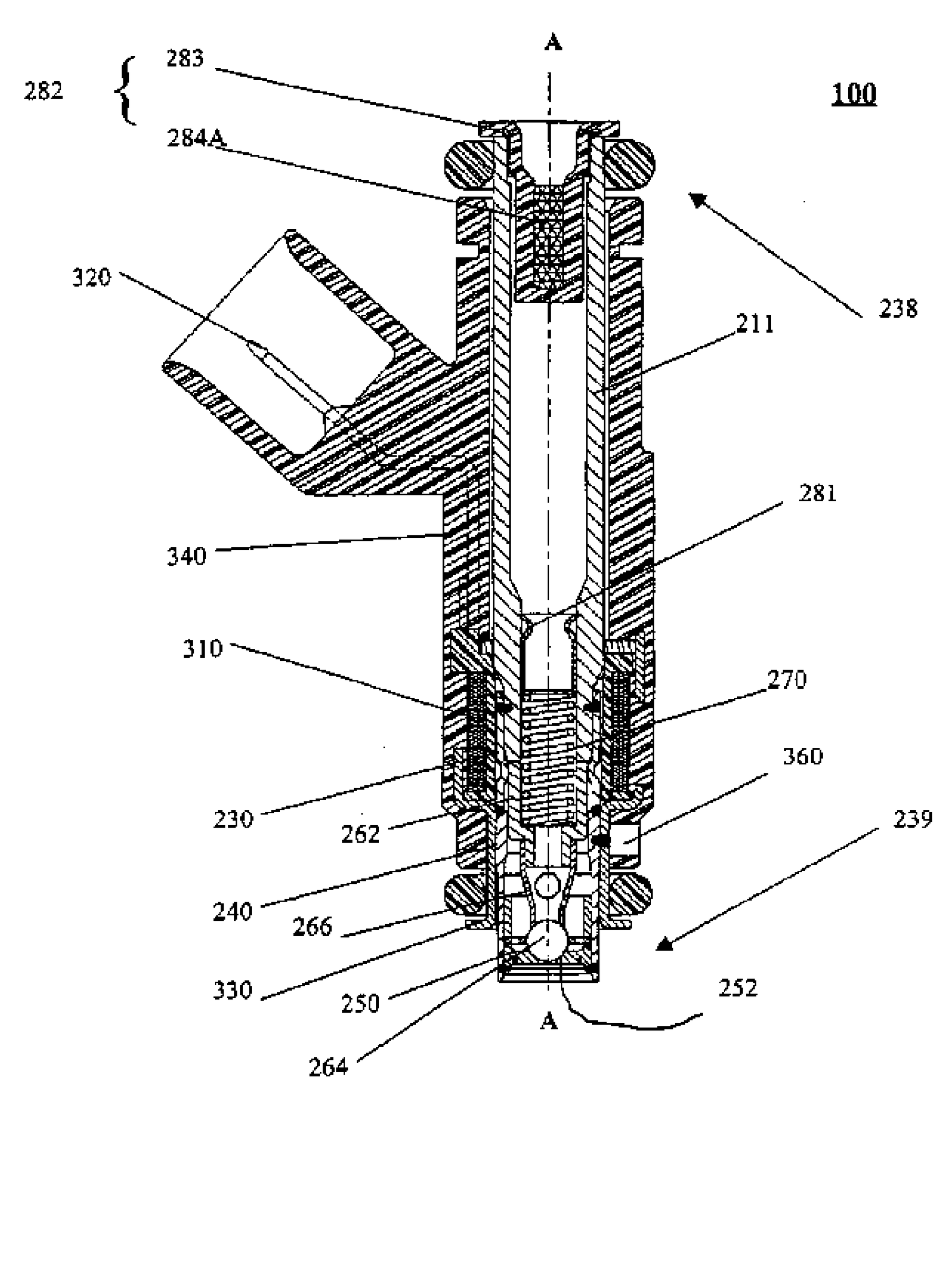
EPO/4P 02 07 622; International Search Report; Oct. 30, 2002.

Primary Examiner—Davis Hwu

(57) **ABSTRACT**

A fuel injector for use with an internal combustion engine. The fuel injector comprises a valve group subassembly and a coil group subassembly. The valve group subassembly includes a tube assembly having a longitudinal axis that extends between a first end and a second end; a seat that is secured at the second end of the tube assembly and that defines an opening; an armature assembly that is disposed within the tube assembly; a member that biases the armature assembly toward the seat; an adjusting tube that is disposed in the tube assembly and that engages the member for adjusting a biasing force of the member; a filter that is at least within the tube assembly; and a first attachment portion. The coil group subassembly includes a solenoid coil that is operable to displace the armature assembly with respect to the seat; and a second attachment portion that is fixedly connected to the first attachment portion.

18 Claims, 23 Drawing Sheets



U.S. PATENT DOCUMENTS

4,662,567	A		5/1987	Knapp	239/585
4,800,912	A	*	1/1989	Hafner et al.	137/15.19
4,875,658	A		10/1989	Asai	
4,915,350	A		4/1990	Babitzka et al.	251/129.15
4,944,486	A		7/1990	Babitzka	251/129.21
4,946,107	A		8/1990	Hunt	239/585
4,984,744	A		1/1991	Babitzka et al.	239/585
4,991,557	A		2/1991	DeGrace et al.	123/470
5,038,738	A		8/1991	Hafner et al.	123/470
5,054,691	A		10/1991	Huang et al.	239/585
5,058,554	A		10/1991	Takeda et al.	123/456
5,076,499	A		12/1991	Cranford	239/585
5,127,585	A		7/1992	Mesenich	239/585.55
5,150,842	A	*	9/1992	Hickey	239/585.4
5,167,213	A		12/1992	Bassler et al.	123/470
5,190,221	A		3/1993	Reiter	239/463
5,211,341	A		5/1993	Wieczorek	239/585
5,236,174	A		8/1993	Vogt et al.	251/129.21
5,263,648	A		11/1993	Vogt et al.	239/585.4
5,275,341	A		1/1994	Romann et al.	239/585.4
5,340,032	A		8/1994	Stegmaier et al.	239/575
5,462,231	A		10/1995	Hall	239/585.4
5,494,224	A		2/1996	Hall et al.	239/585.5
5,494,225	A		2/1996	Nally et al.	239/585.5
5,520,151	A		5/1996	Gras et al.	123/470
5,544,816	A		8/1996	Nally et al.	239/585.5
5,566,920	A		10/1996	Romann et al.	251/129.21
5,580,001	A		12/1996	Romann et al.	239/585.4
5,692,723	A		12/1997	Baxter et al.	137/15
5,718,387	A		2/1998	Awarzamani et al.	239/585.1
5,732,888	A		3/1998	Maier et al.	239/585.1
5,755,386	A		5/1998	Lavan et al.	239/585.4
5,769,391	A		6/1998	Noller et al.	251/129.21
5,769,965	A		6/1998	Liedtke et al.	148/121
5,775,355	A		7/1998	Maier et al.	137/15
5,775,600	A		7/1998	Wildeson et al.	239/585.4
5,875,975	A		3/1999	Reiter et al.	239/585.1
5,901,688	A		5/1999	Balsdon et al.	123/516
5,915,626	A		6/1999	Awarzamani et al.	239/135
5,921,475	A	*	7/1999	DeVriese et al.	239/585.4
5,927,613	A		7/1999	Koyanagi et al.	239/585.1
5,937,887	A		8/1999	Baxter et al.	137/15
5,944,262	A		8/1999	Akutagawa et al.	239/585.4
5,975,436	A		11/1999	Reiter et al.	239/585.1
5,979,411	A		11/1999	Ricco	123/469
5,979,866	A		11/1999	Baxter et al.	251/129.21
5,996,227	A		12/1999	Reiter et al.	29/888.45
5,996,910	A		12/1999	Takeda et al.	239/585.1
5,996,911	A		12/1999	Gesk et al.	239/585.1
6,003,790	A		12/1999	Fly	239/533.9
6,012,655	A		1/2000	Maier et al.	239/585.4
6,019,128	A		2/2000	Reiter	137/549
6,027,049	A		2/2000	Stier	239/585.1
6,039,271	A		3/2000	Reiter	137/549
6,039,272	A		3/2000	Ren et al.	239/597
6,045,116	A		4/2000	Willke et al.	251/129.21
6,049,907	A		4/2000	Palomo	239/585.1
6,076,802	A		6/2000	Maier	251/129.21
6,079,642	A		6/2000	Maier	239/585.1
6,089,467	A		7/2000	Fochtman et al.	239/5
6,089,475	A		7/2000	Reiter et al.	239/585.1
6,168,098	B1	*	1/2001	Brinn, Jr.	239/585.4
6,170,763	B1	*	1/2001	Fuchs et al.	239/533.12
6,186,421	B1	*	2/2001	Wahba et al.	239/585.1
6,186,472	B1		2/2001	Reiter	251/129.21
6,189,816	B1	*	2/2001	Stier	239/533.2
6,201,461	B1		3/2001	Eichendorf et al.	335/256
6,328,232	B1		12/2001	Haltiner, Jr. et al.	239/585.1
2001/0017327	A1		8/2001	Fochtman	239/595.4
2001/0048091	A1		12/2001	Enomoto et al.	251/129.15

* cited by examiner

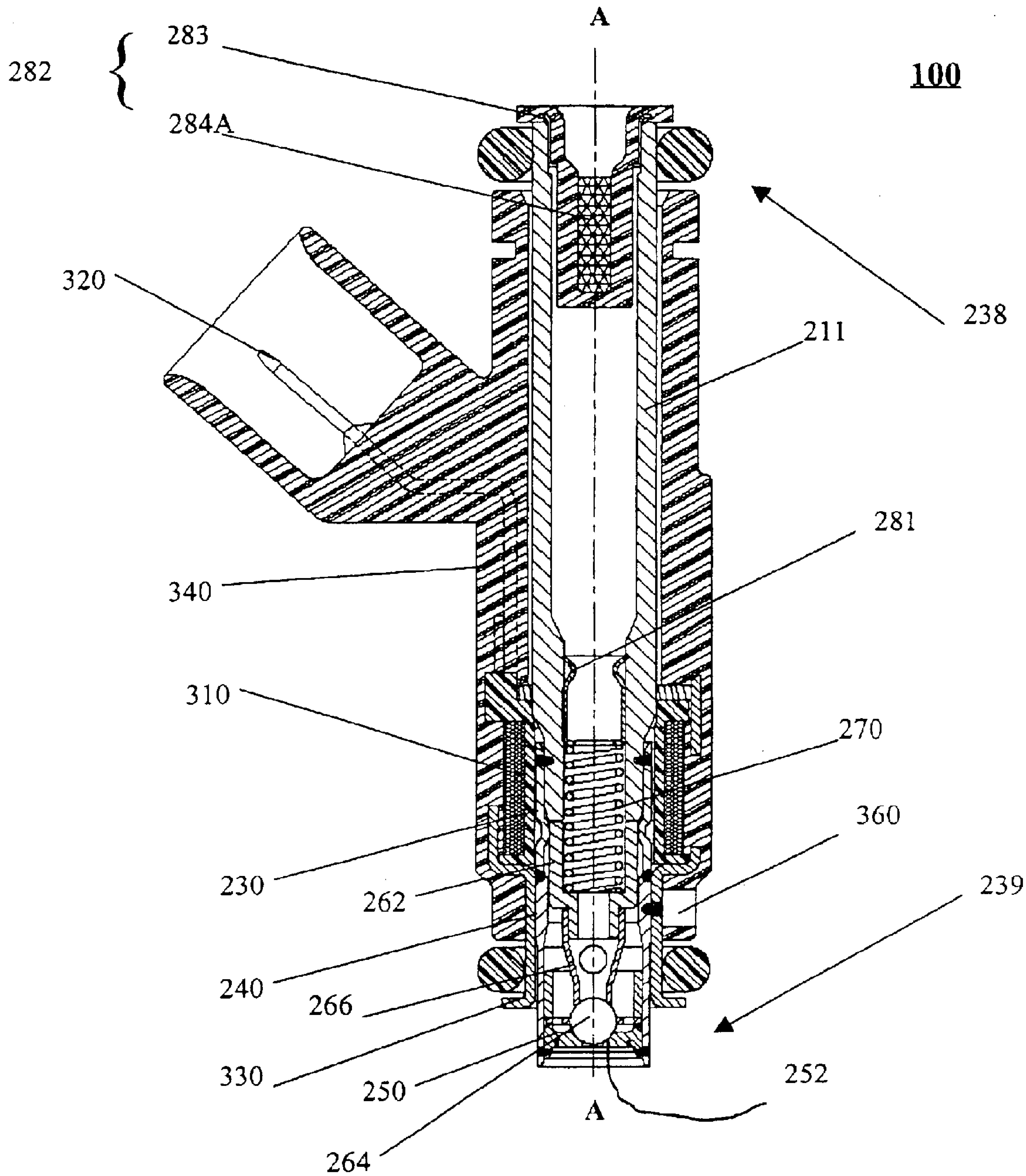

A
283
282
284A
100
320
238
211
281
340
310
270
360
230
262
239
240
266
330
250
252
A
264

FIG. 1

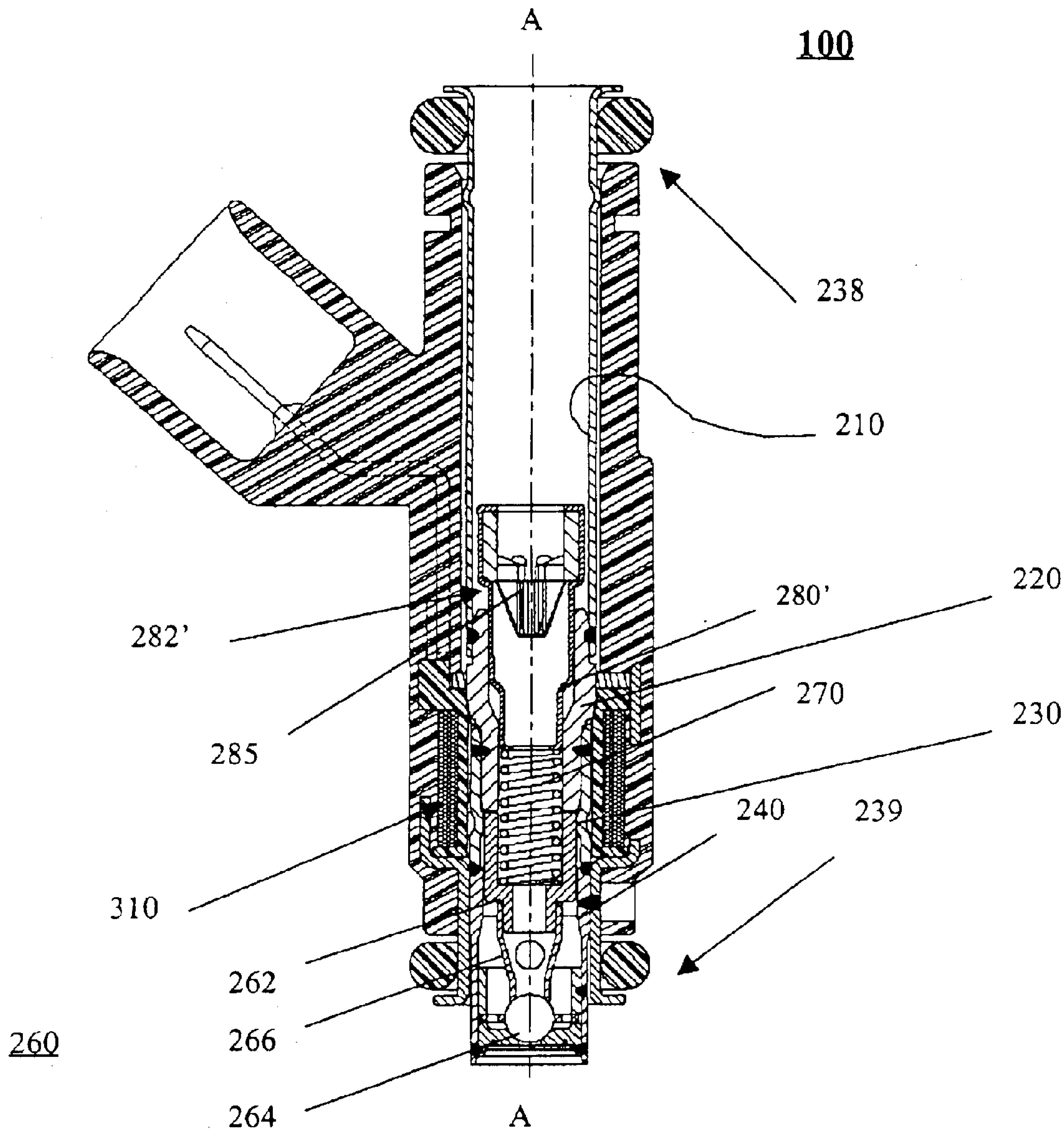

A
100
238
210
220
280'
282'
285
270
230
240
239
310
262
266
260
264
A

FIG. 1A

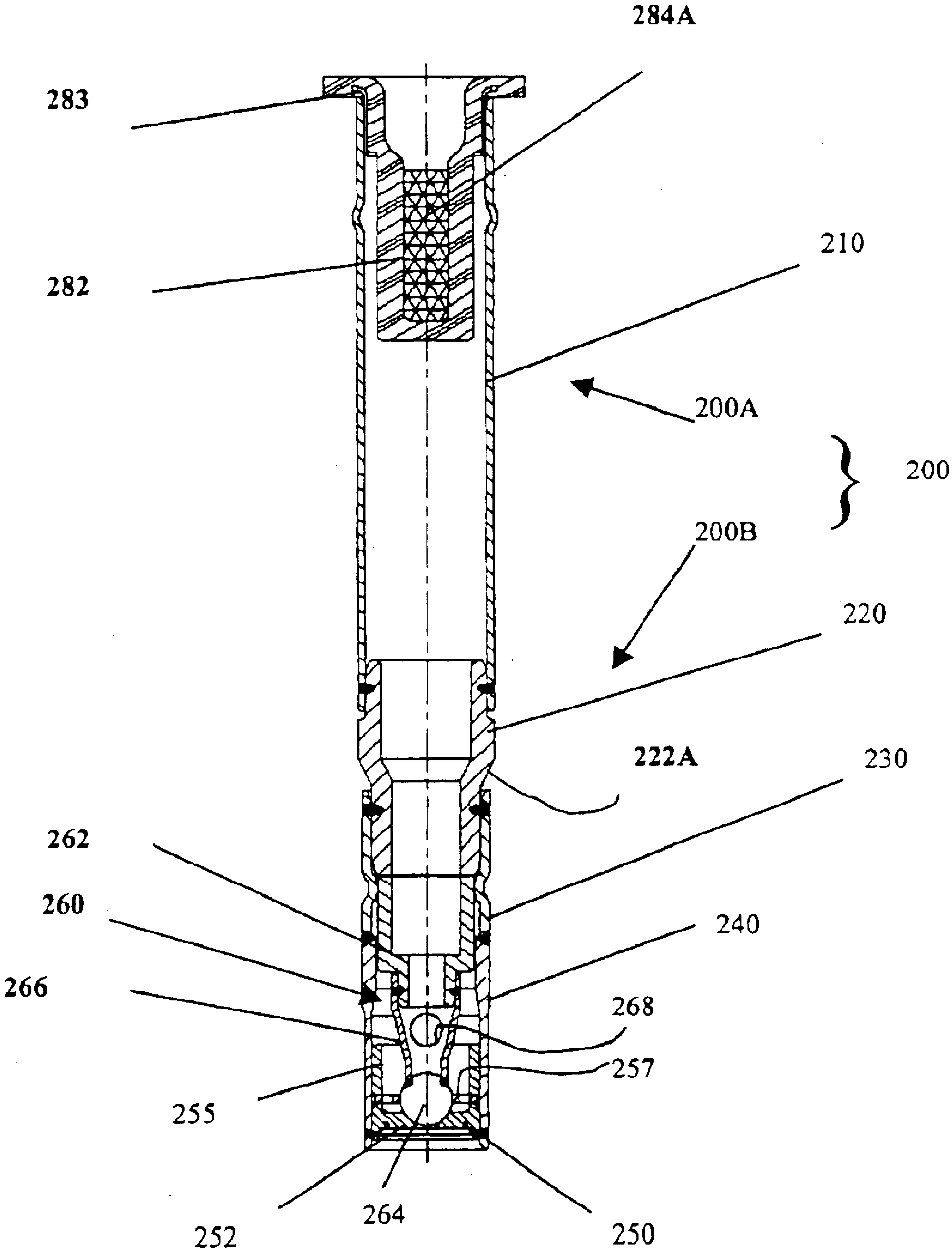

284A
283
282
210
200A
200
200B
220
222A
230
262
260
240
266
268
257
255
264
252
250

FIG. 2

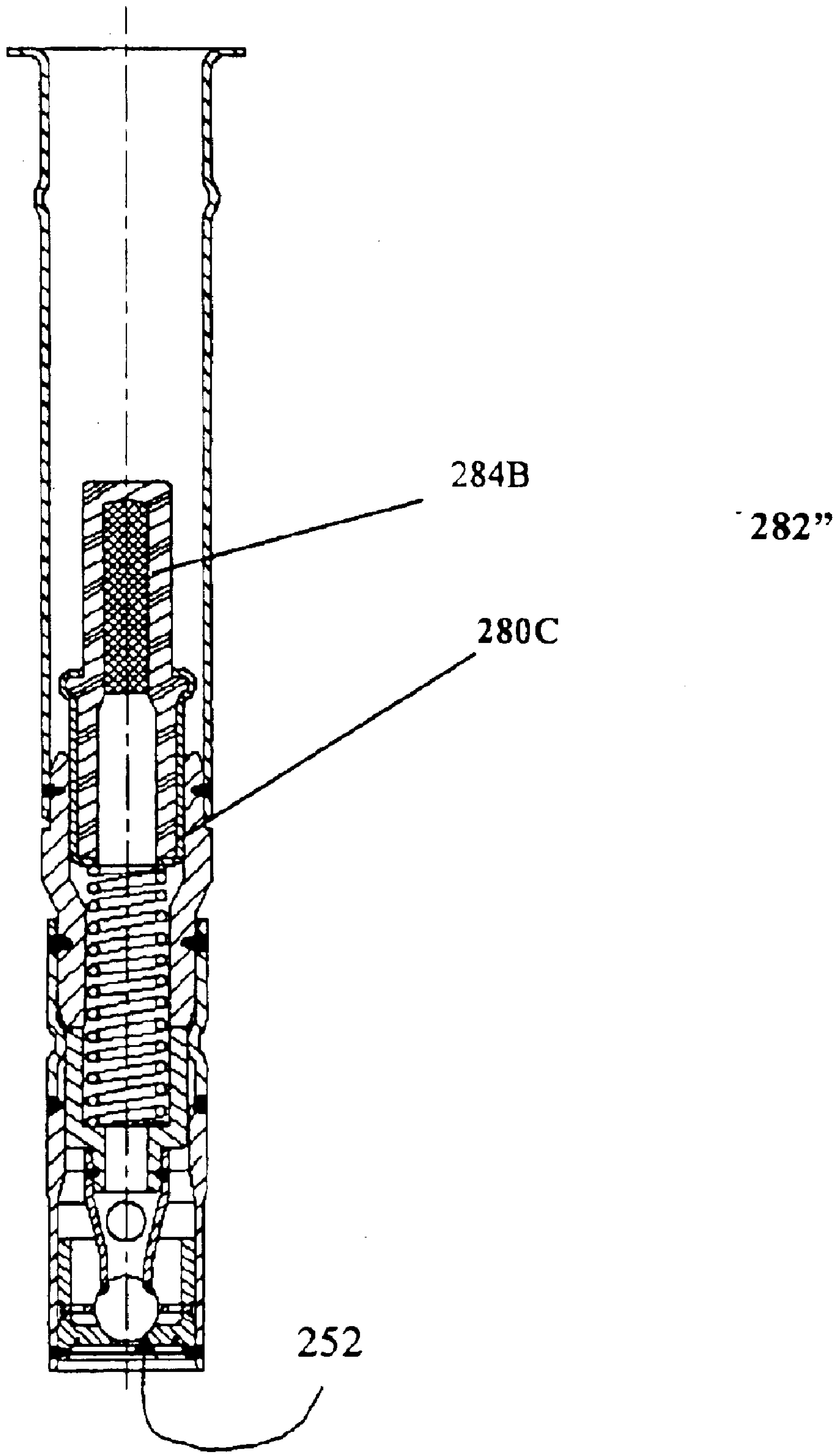


FIG. 2A

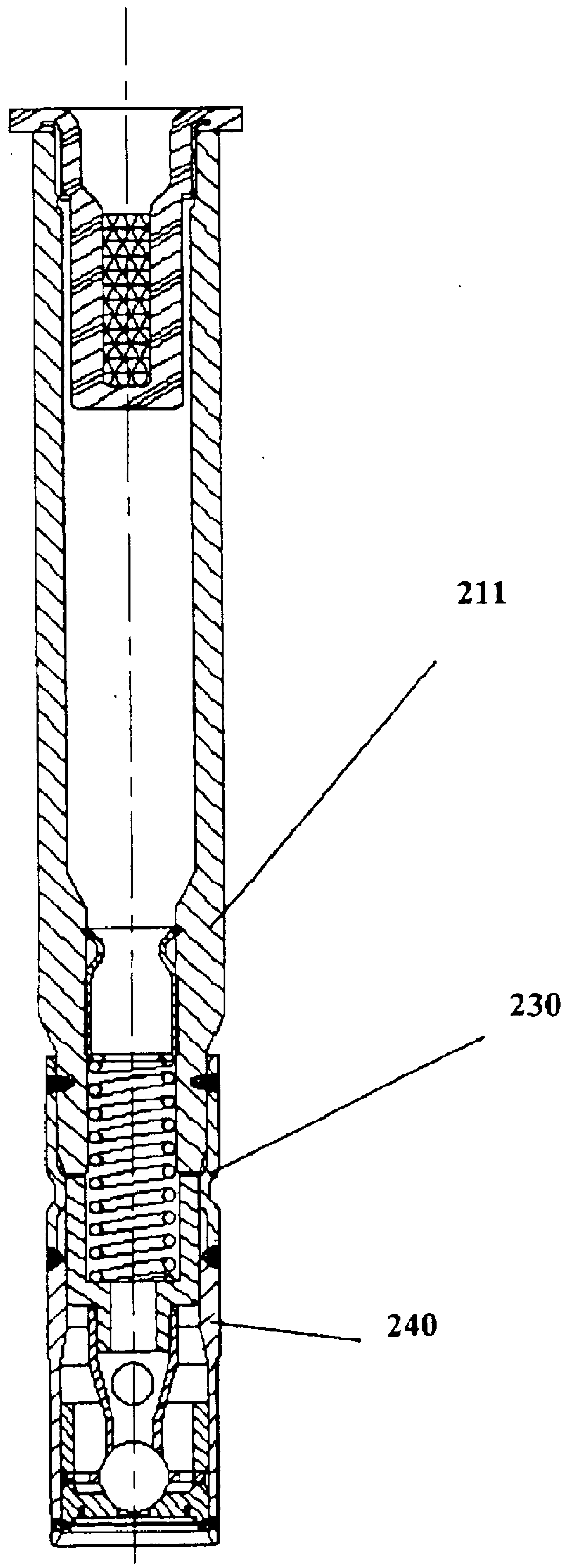


FIG. 2B

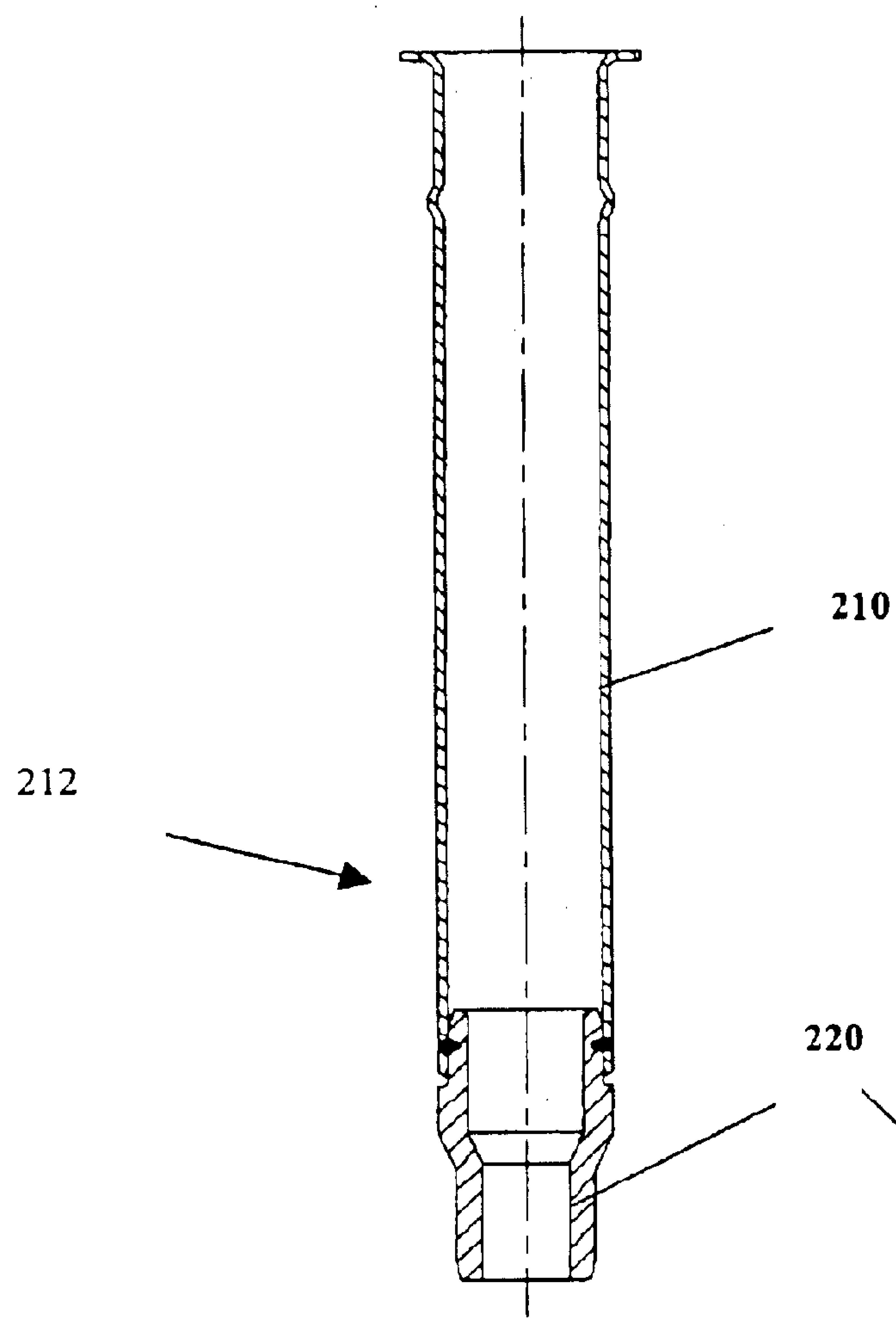


FIG. 2C

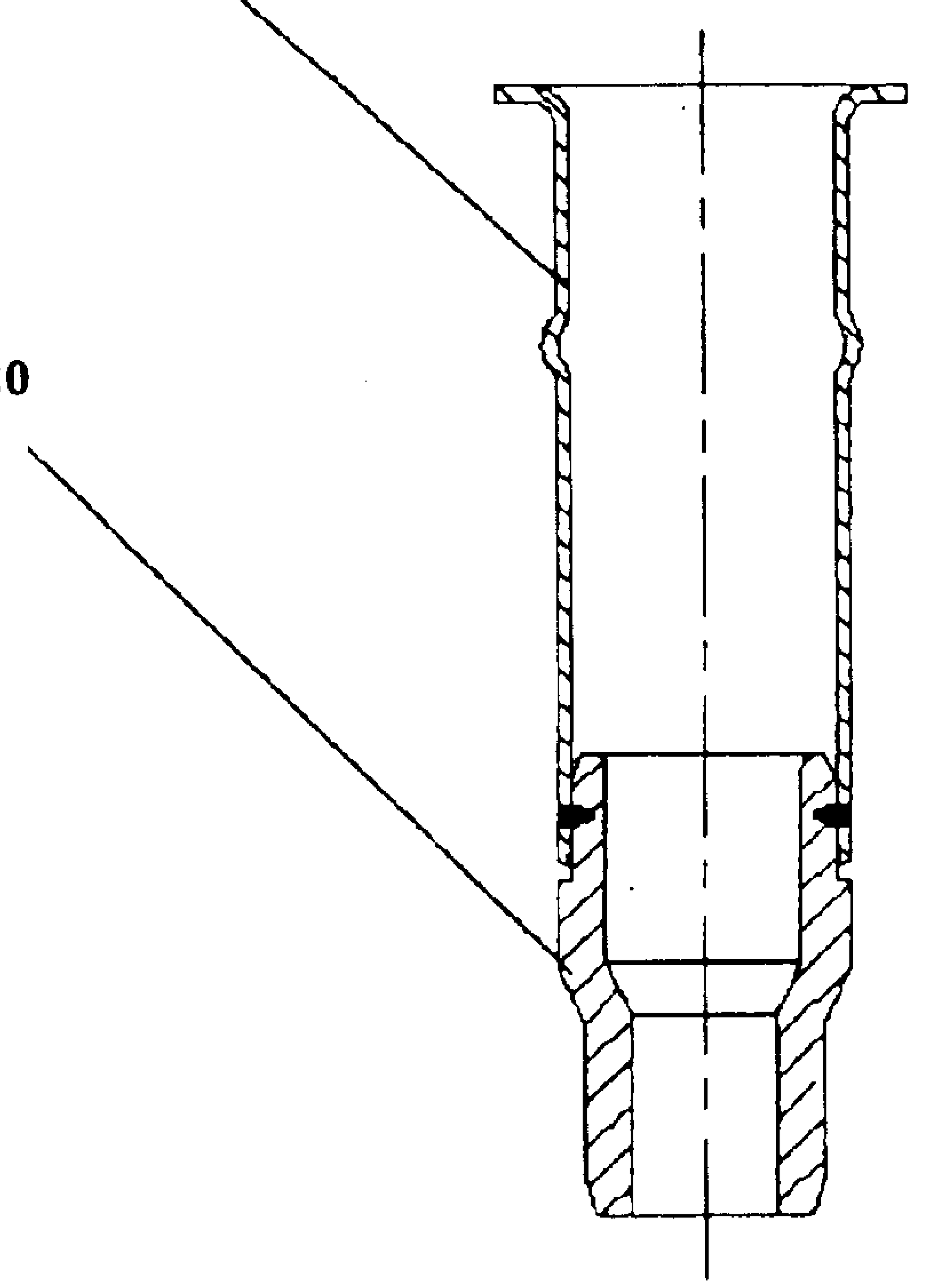


FIG. 2D

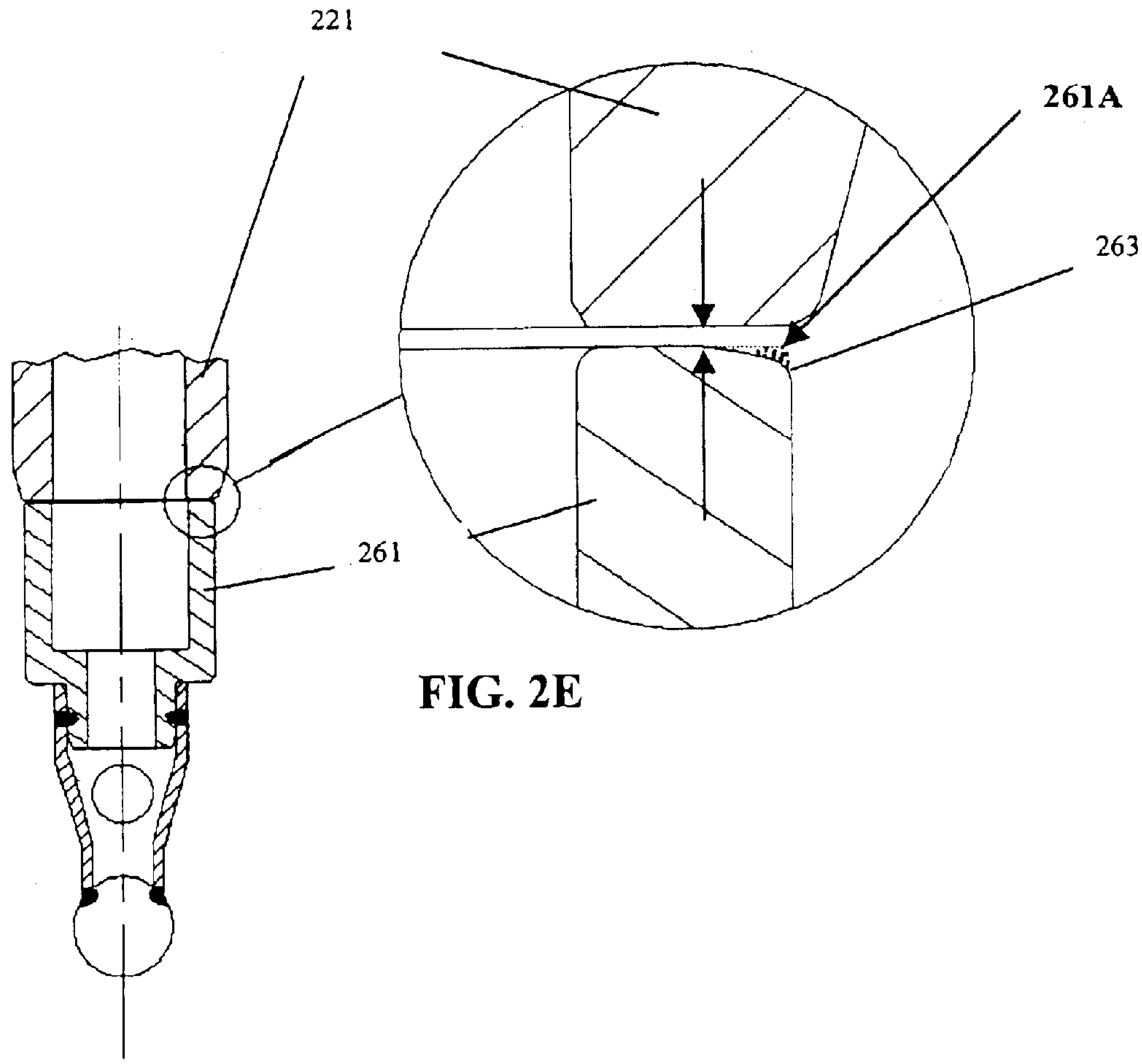
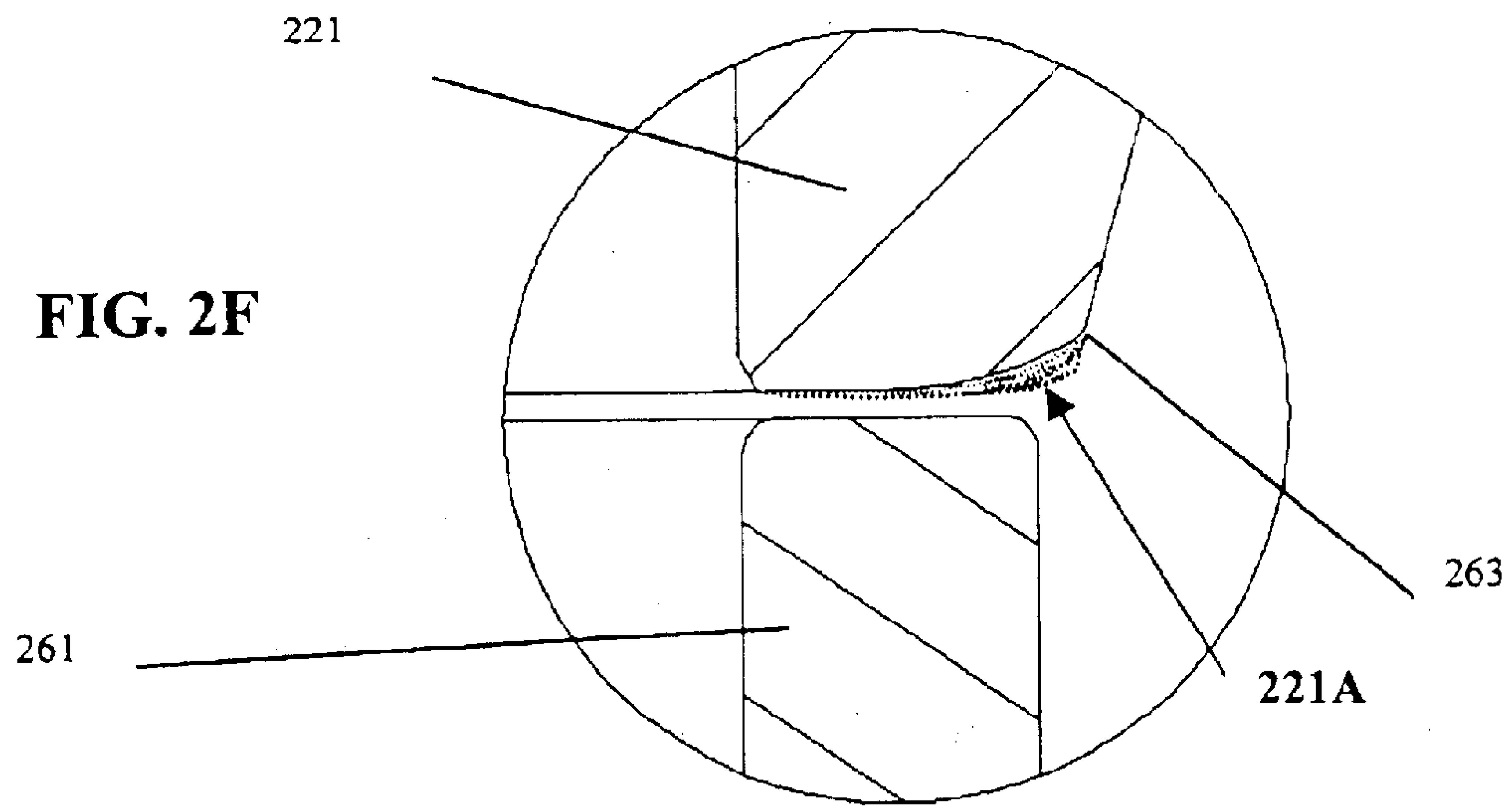


FIG. 2E

FIG. 2F



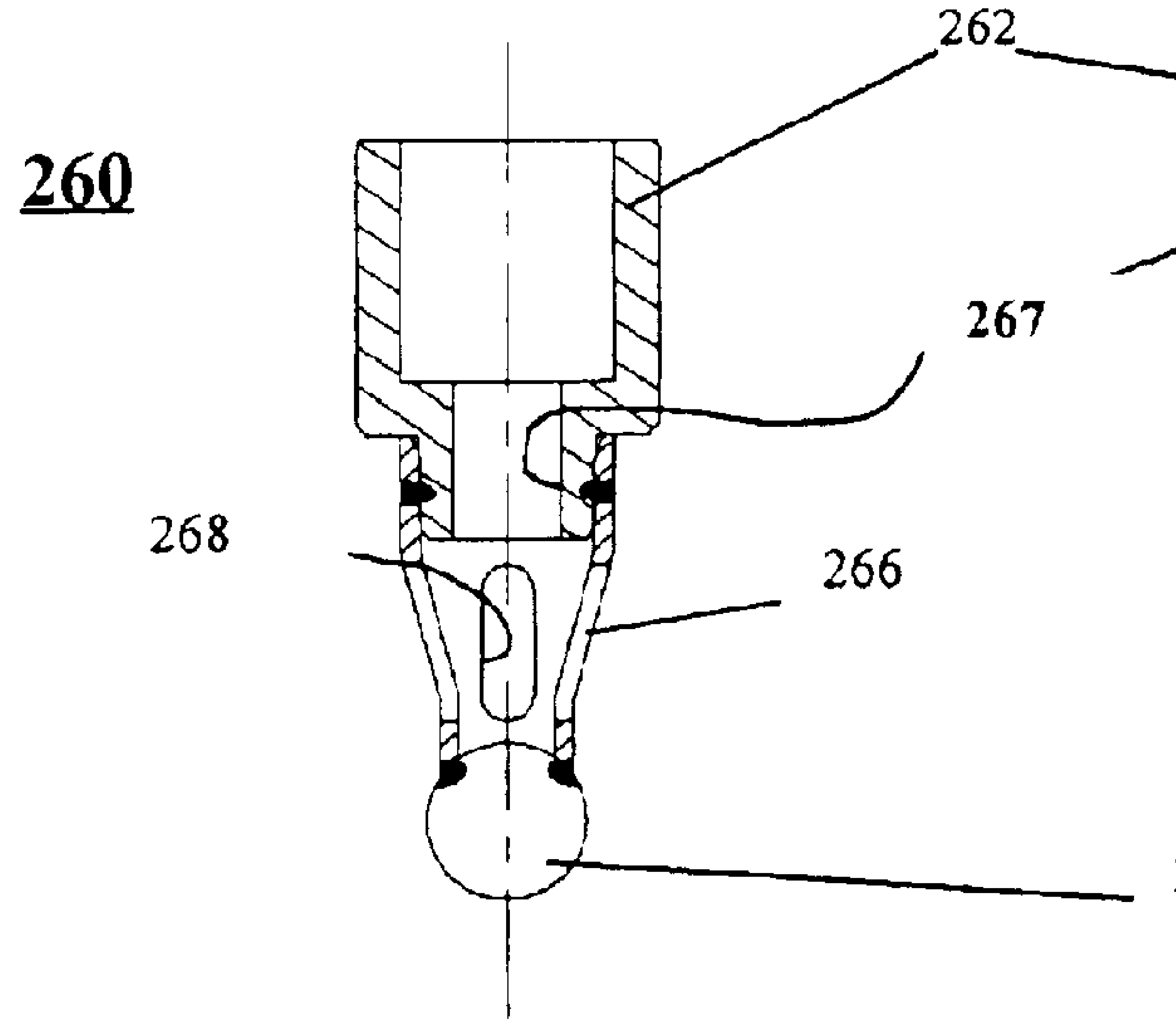


FIG. 2G

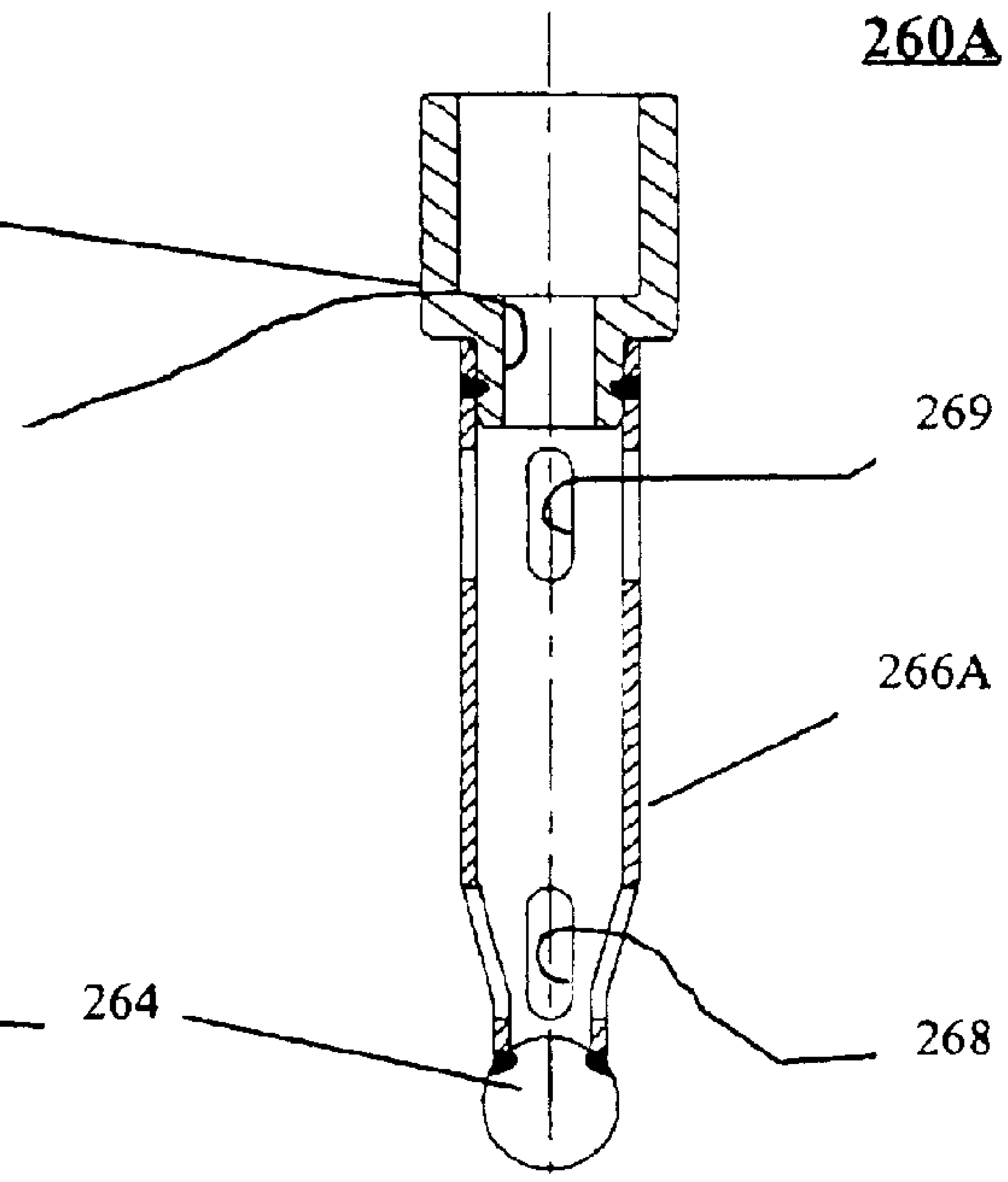


FIG. 2H

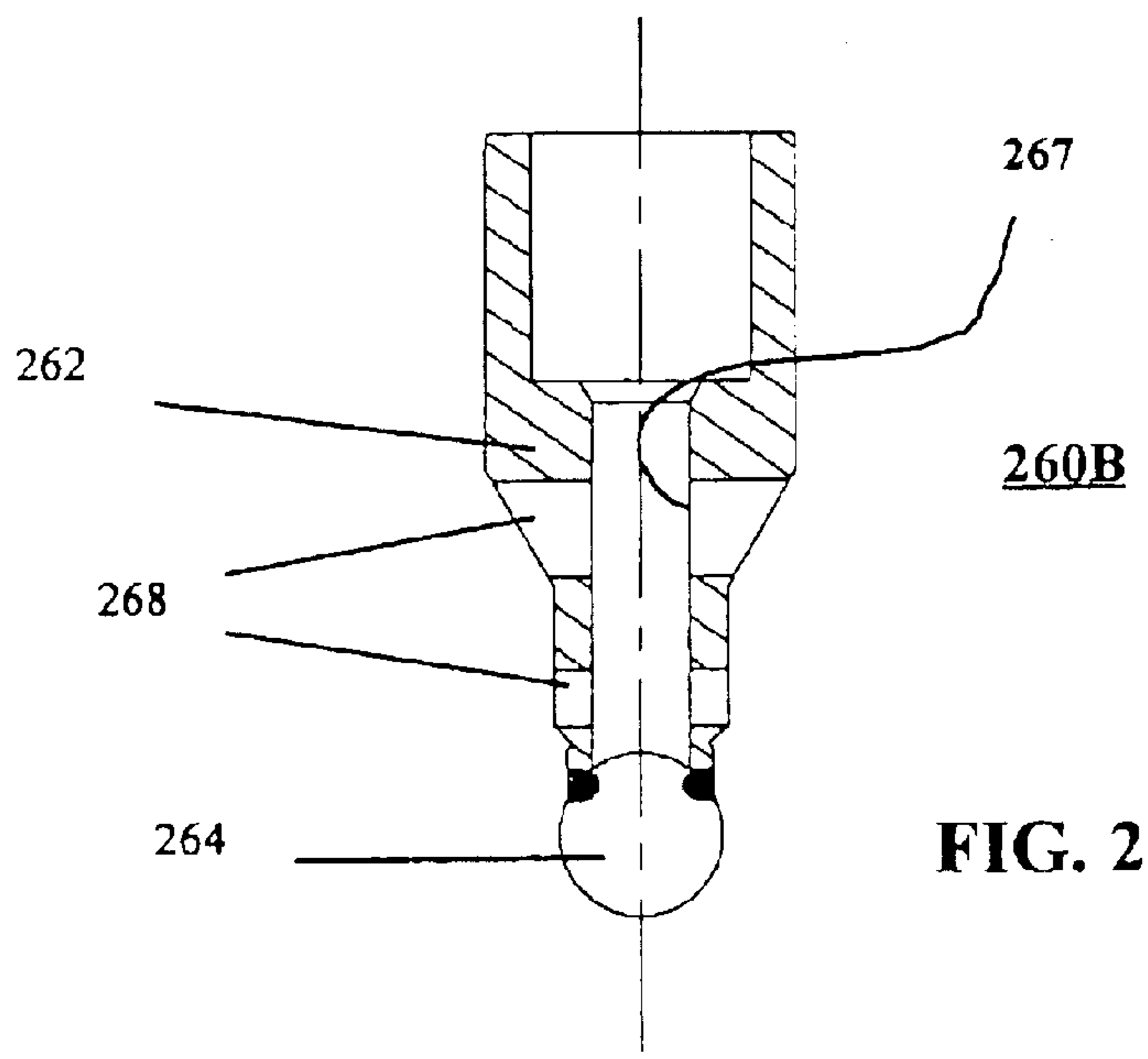


FIG. 2I

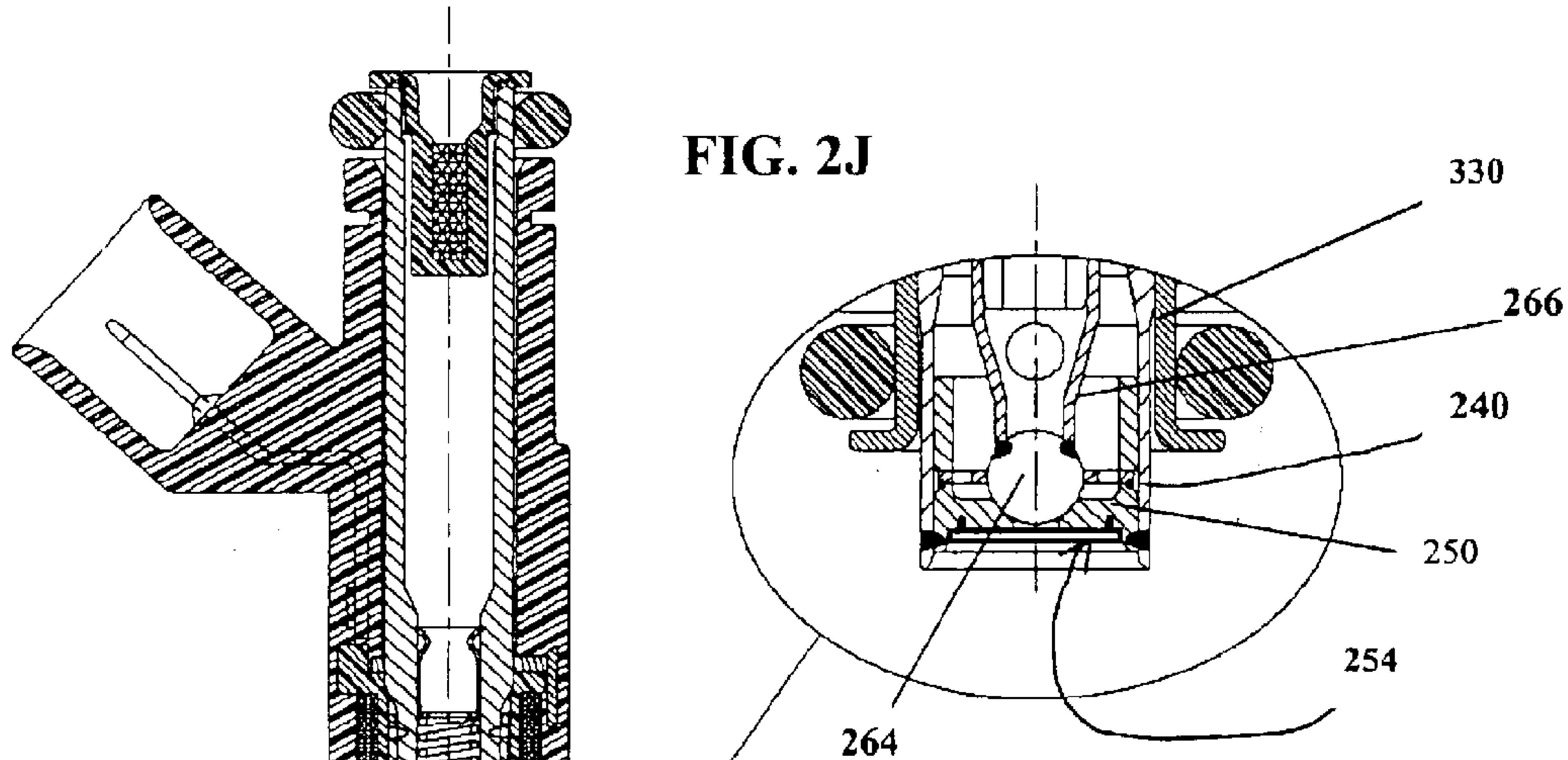


FIG. 2J

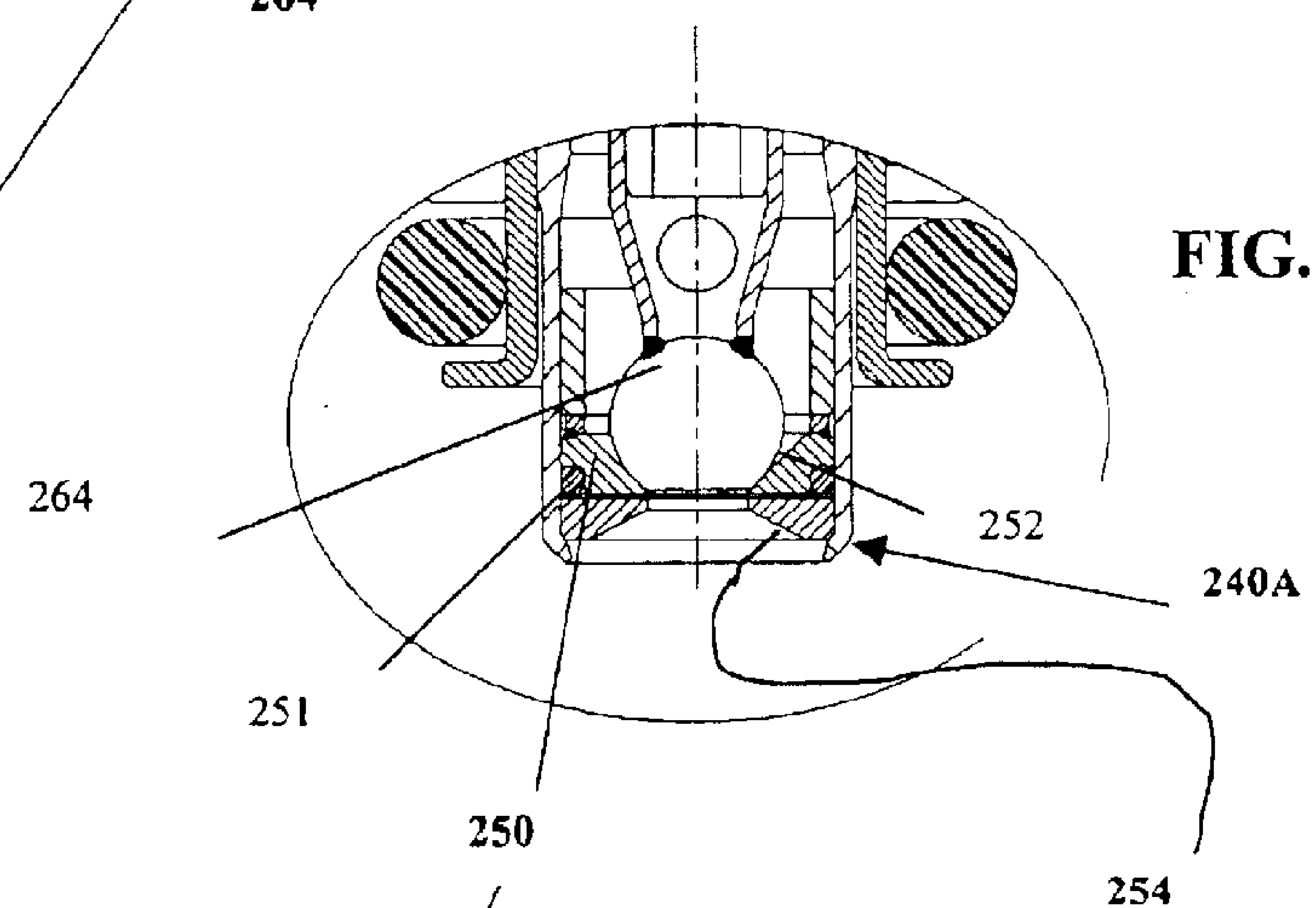


FIG. 2K

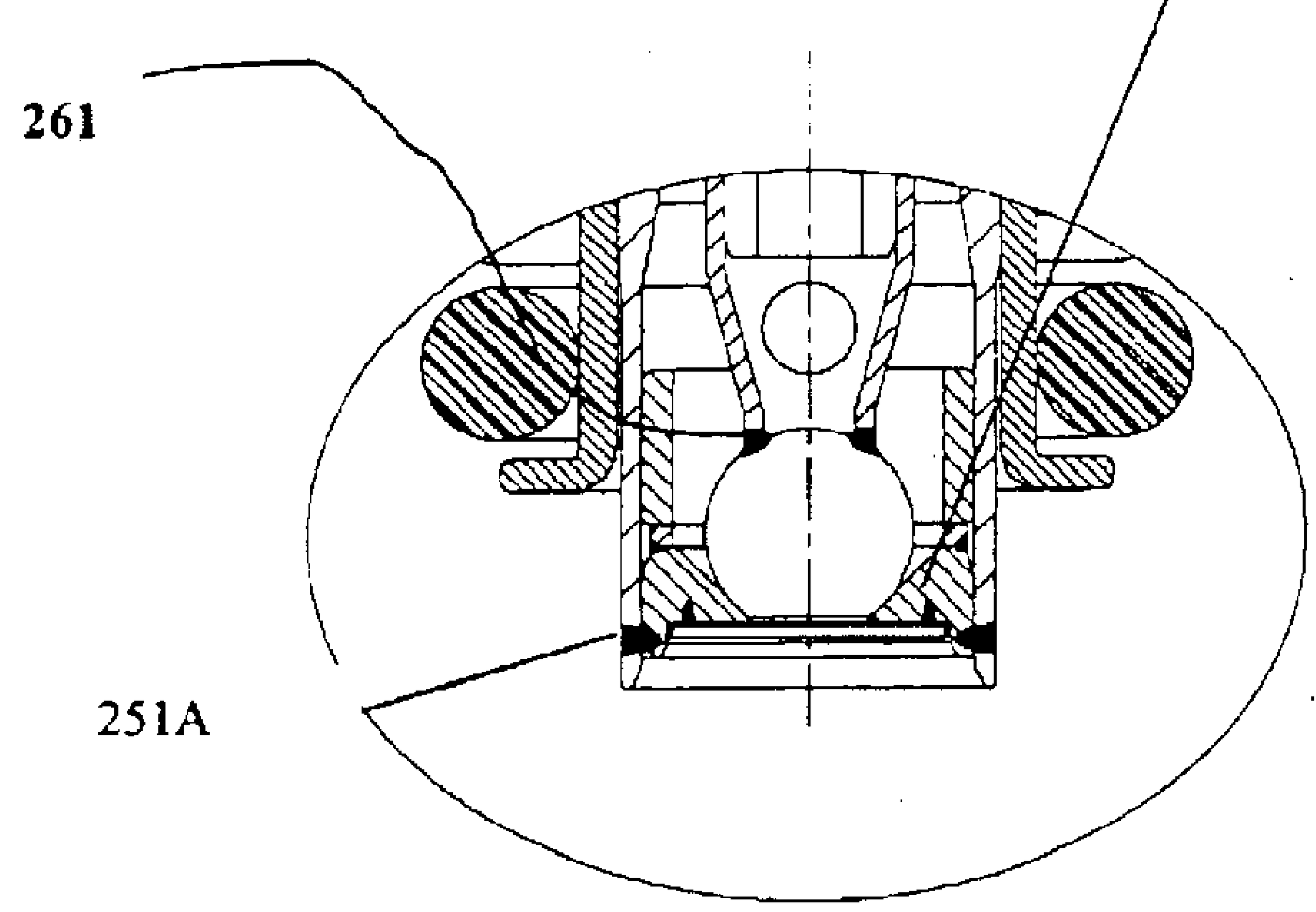


FIG. 2L

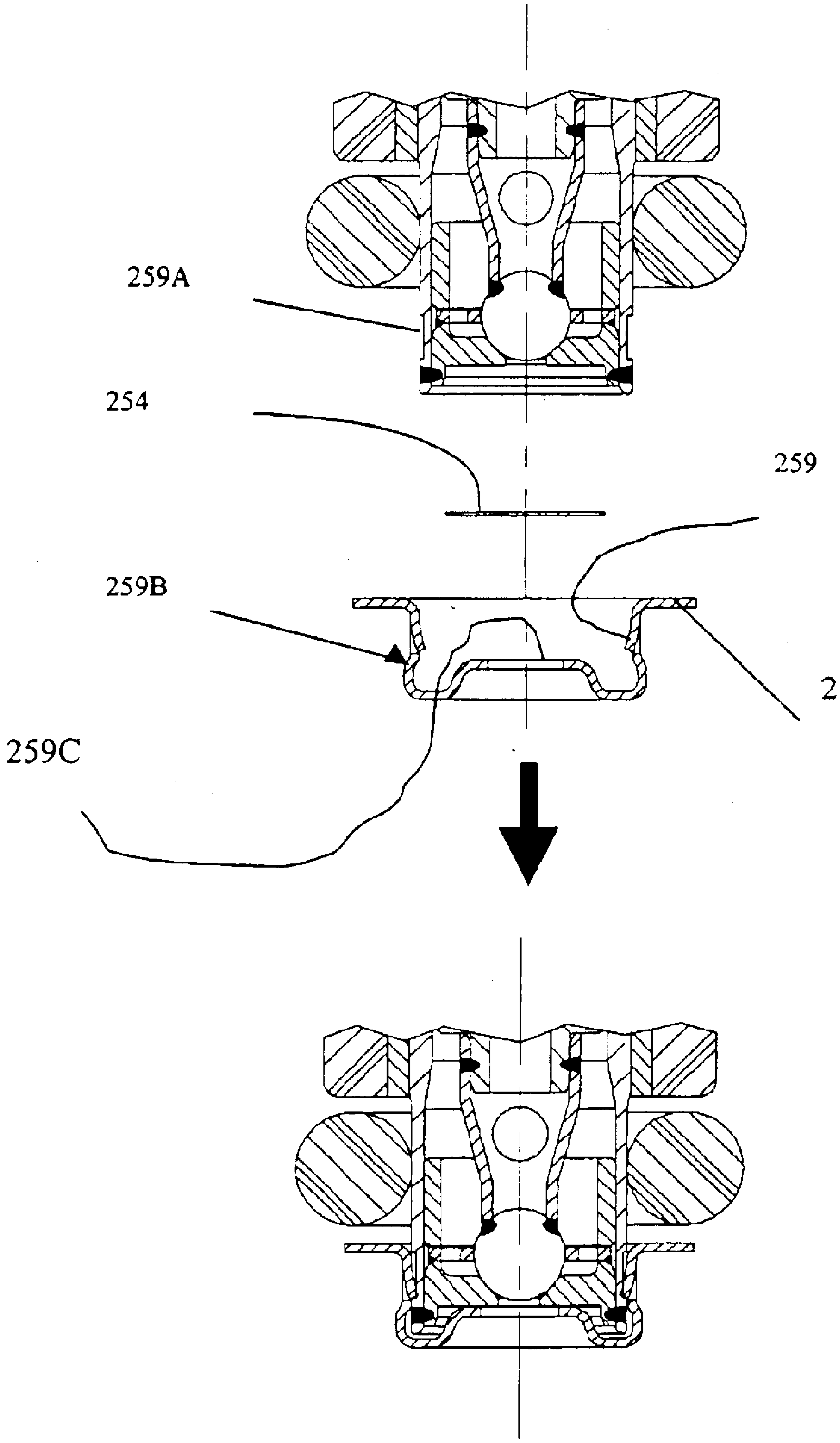


FIG. 2M

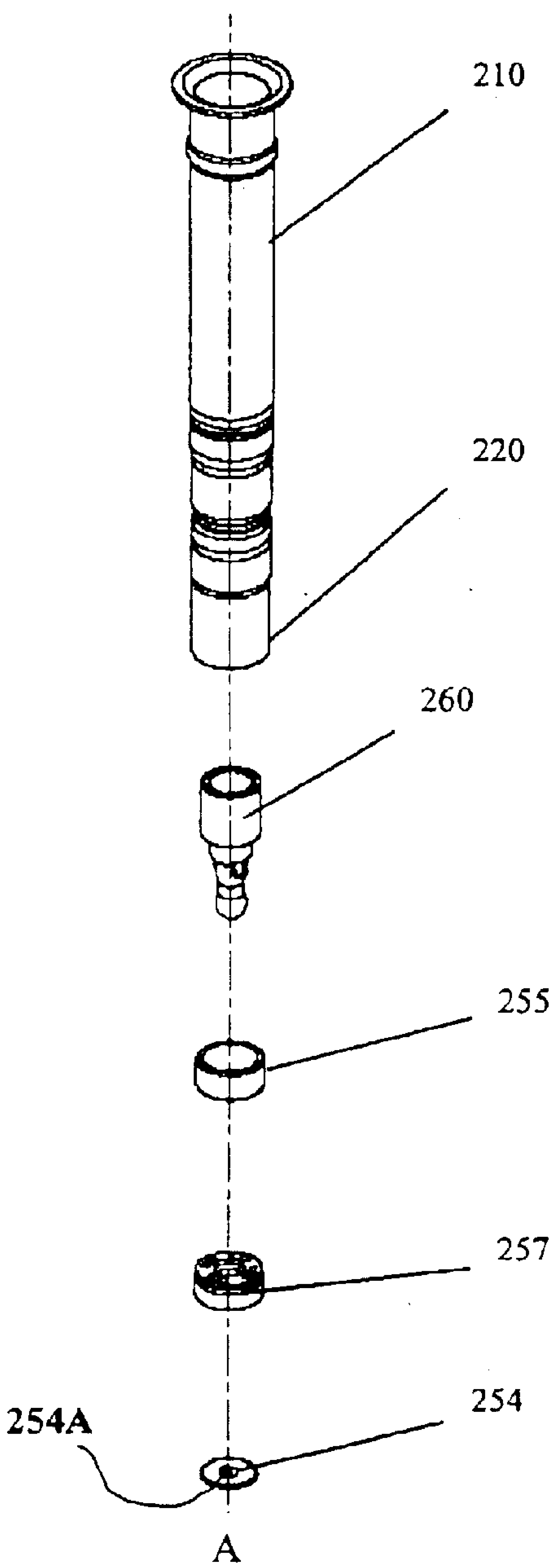


FIG. 2N

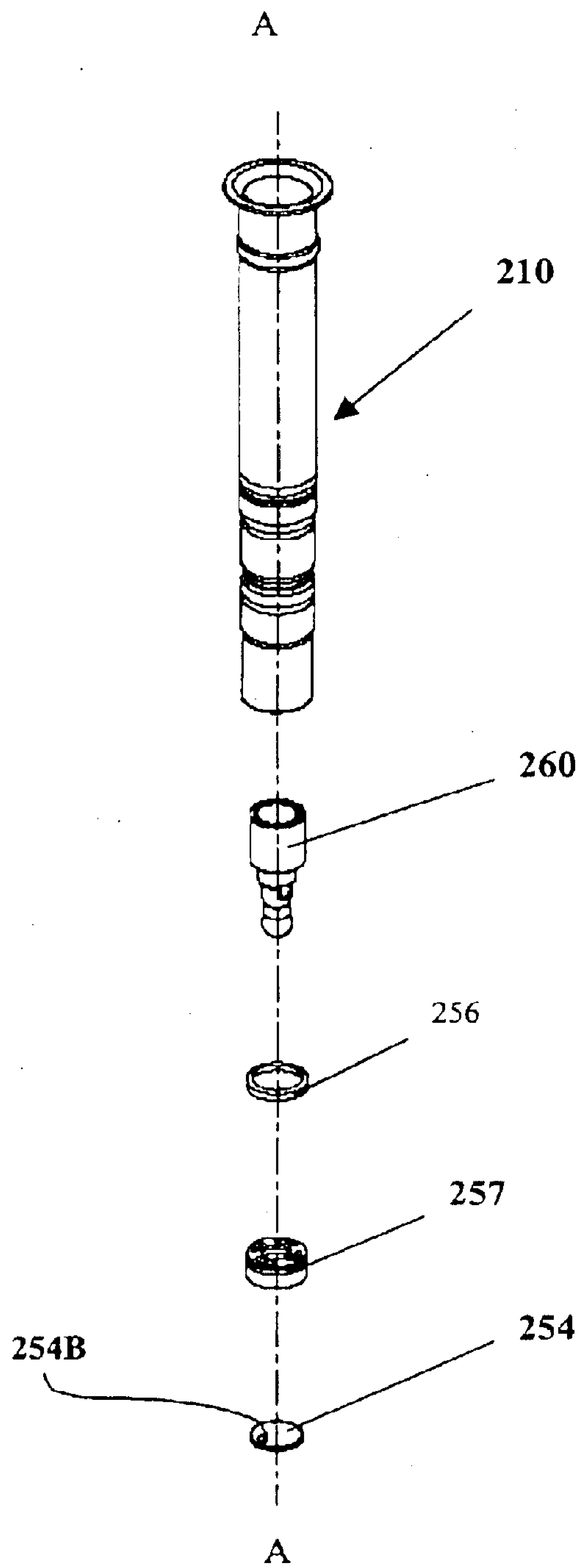


FIG. 2O

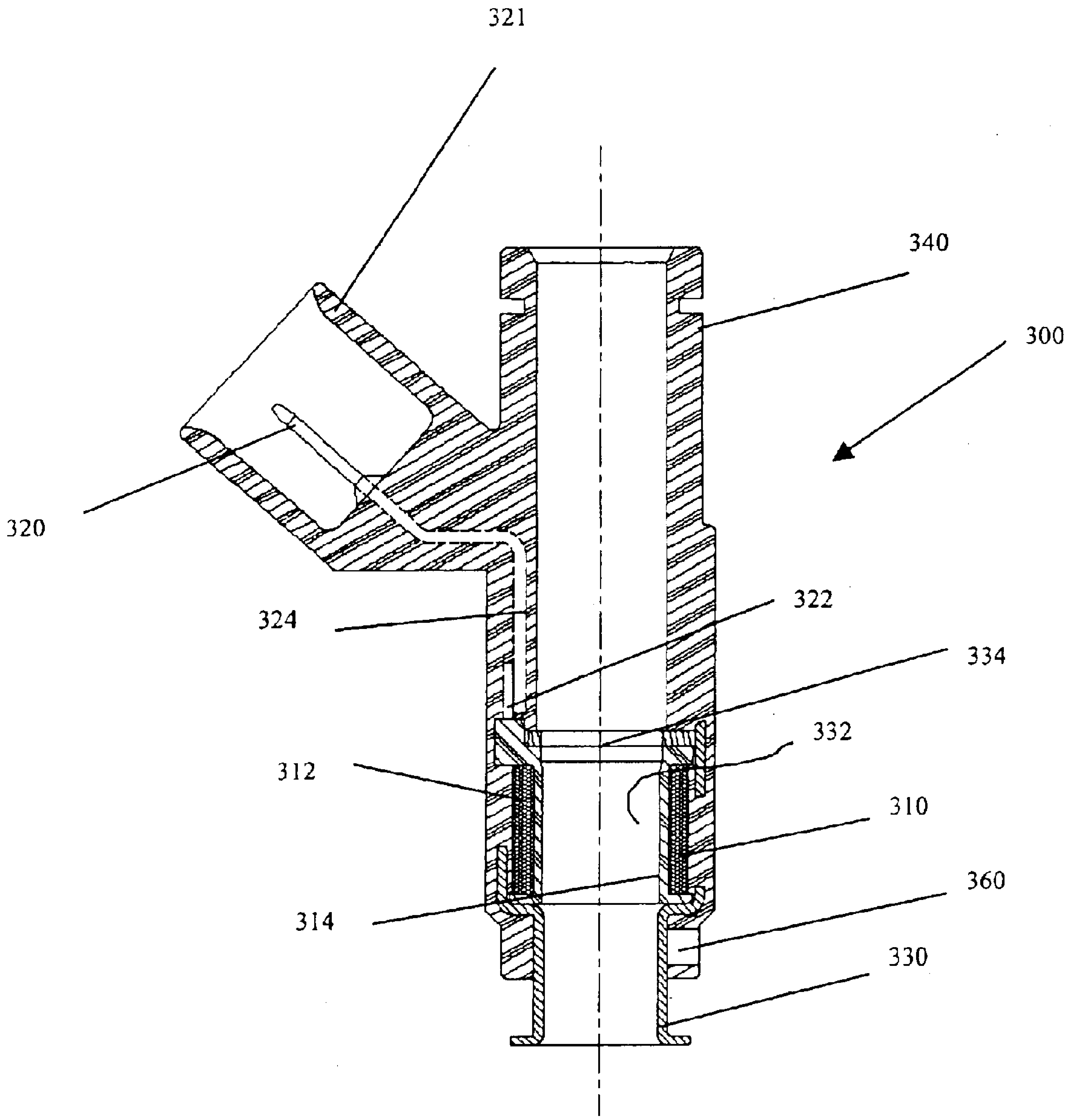


FIG. 3

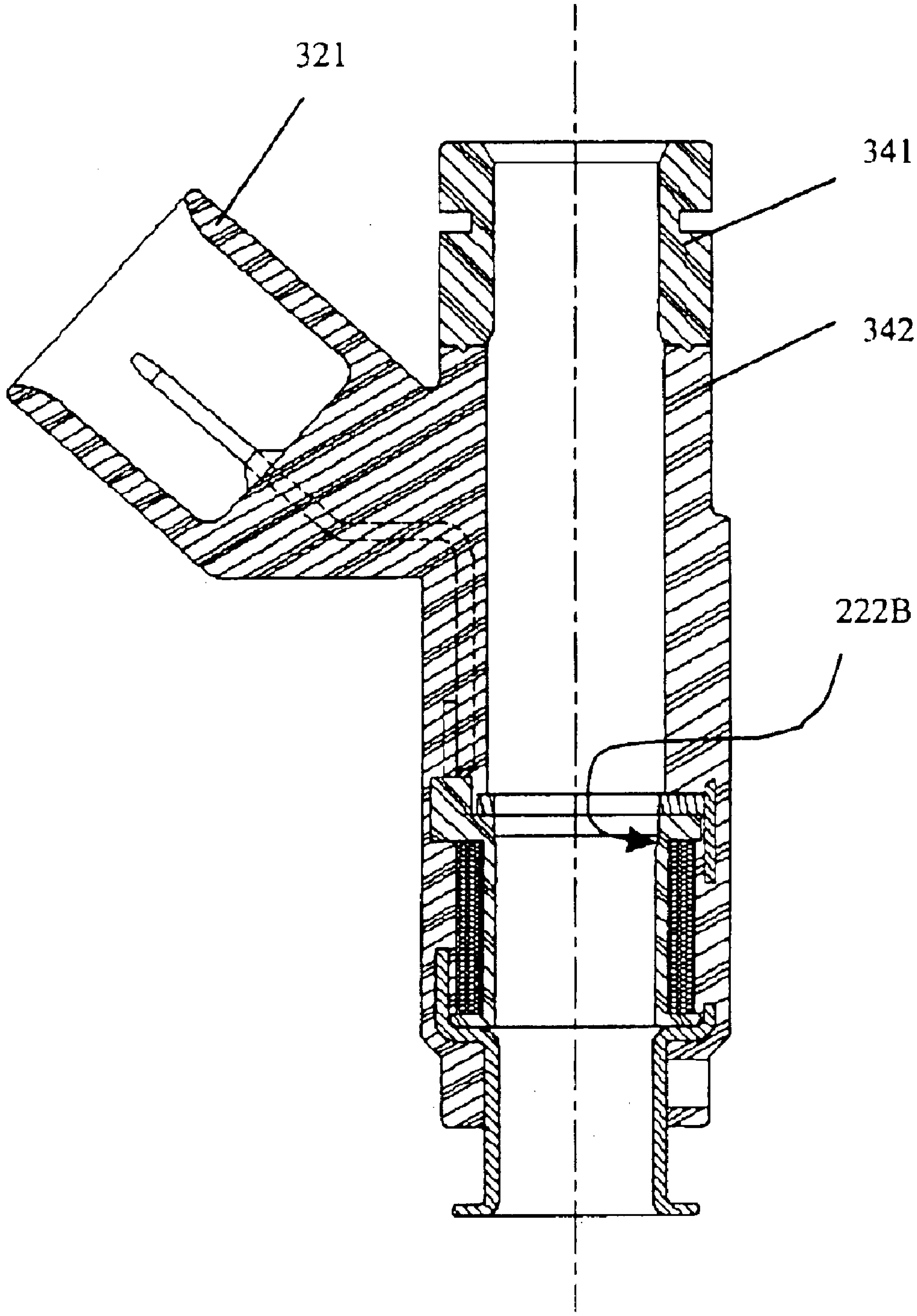


FIG. 3A

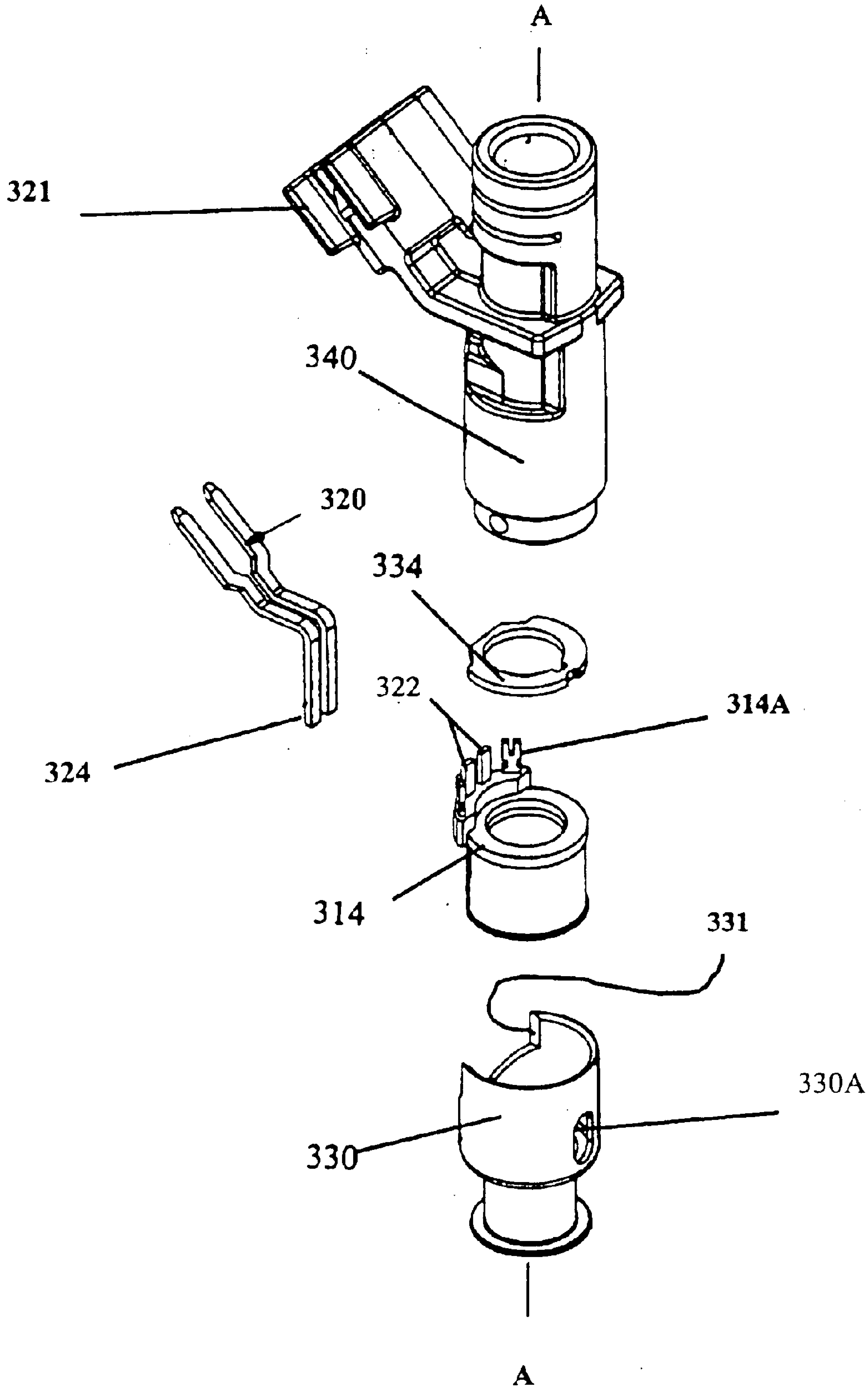


FIG. 3B

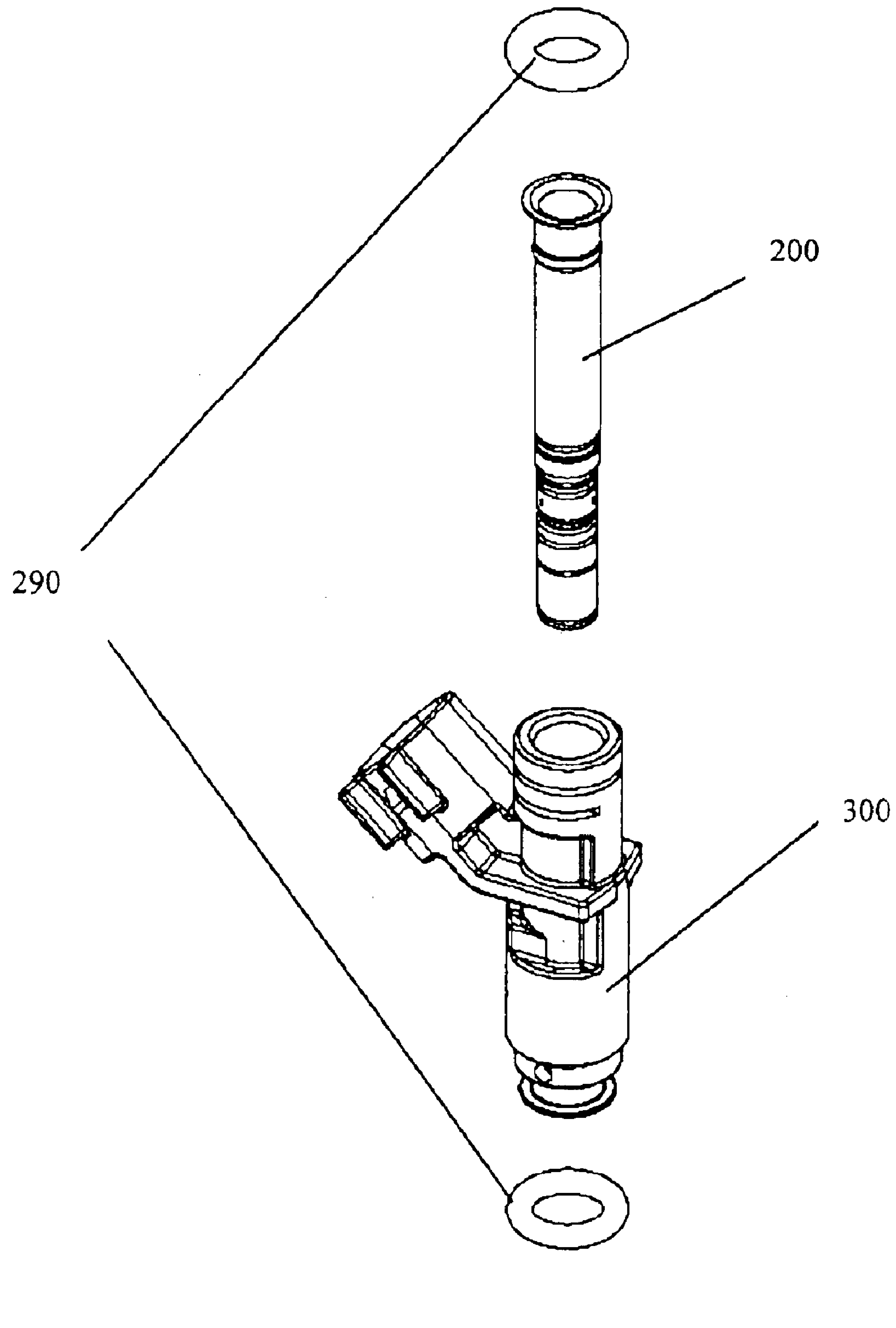


FIG. 4

FIG. 4A

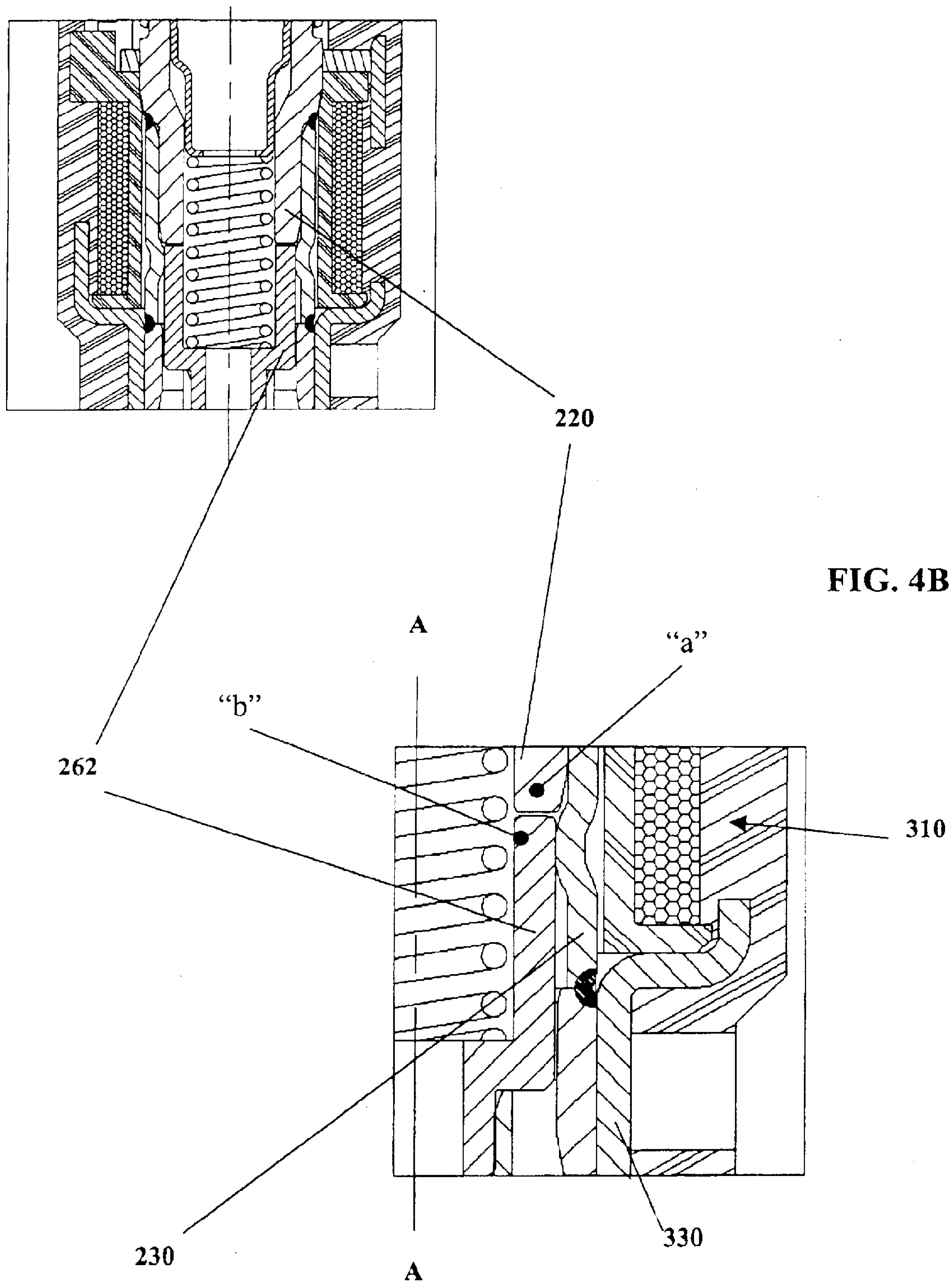
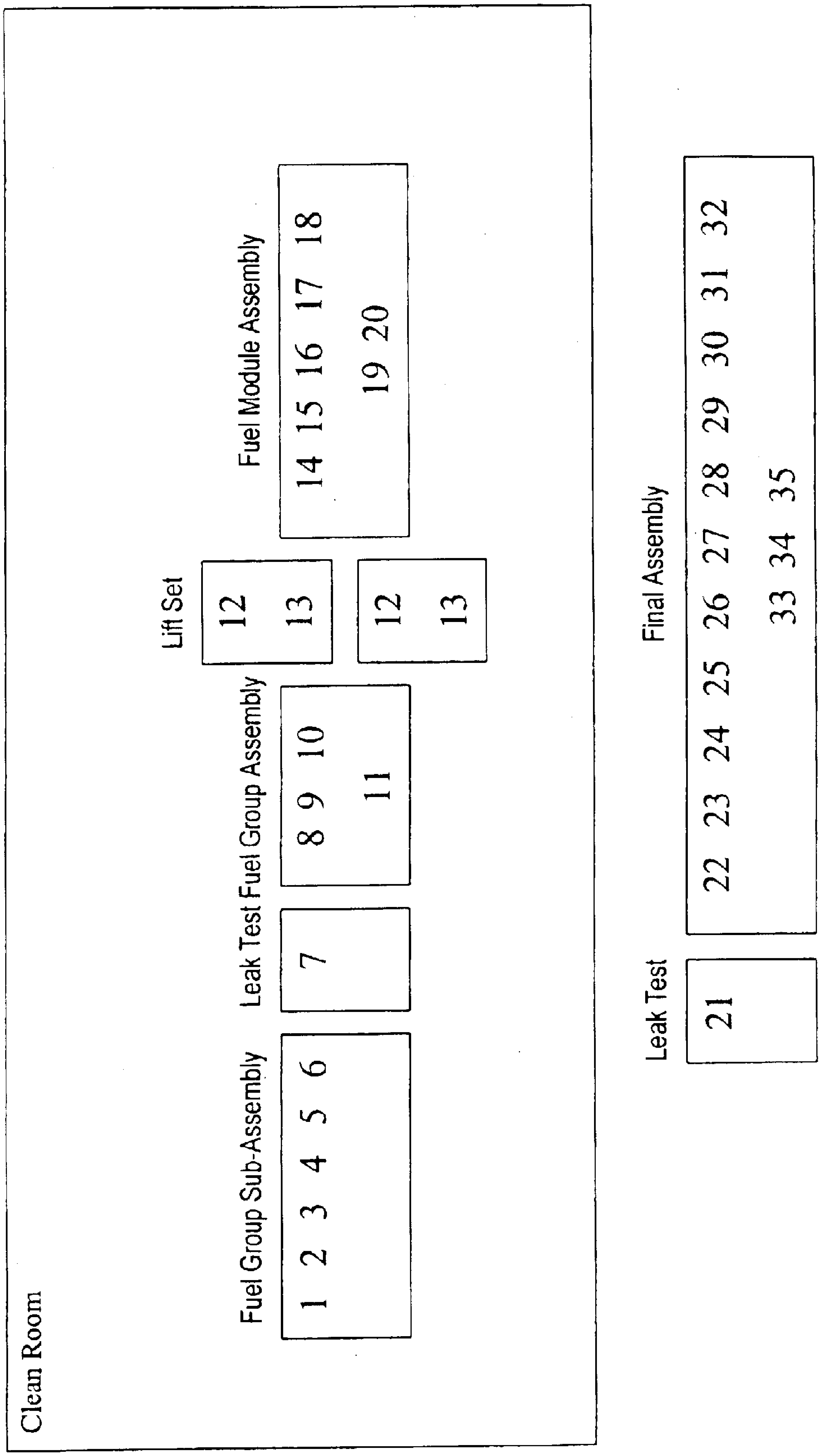


FIG. 4B



Clean Room
Fuel Group Sub-Assembly
1 2 3 4 5 6
Leak Test
7
Fuel Group Assembly
8 9 10
11
Lift Set
12
13
12
13
Fuel Module Assembly
14 15 16 17 18
19 20
Leak Test
21
Final Assembly
22 23 24 25 26 27 28 29 30 31 32
33 34 35

FIG. 5

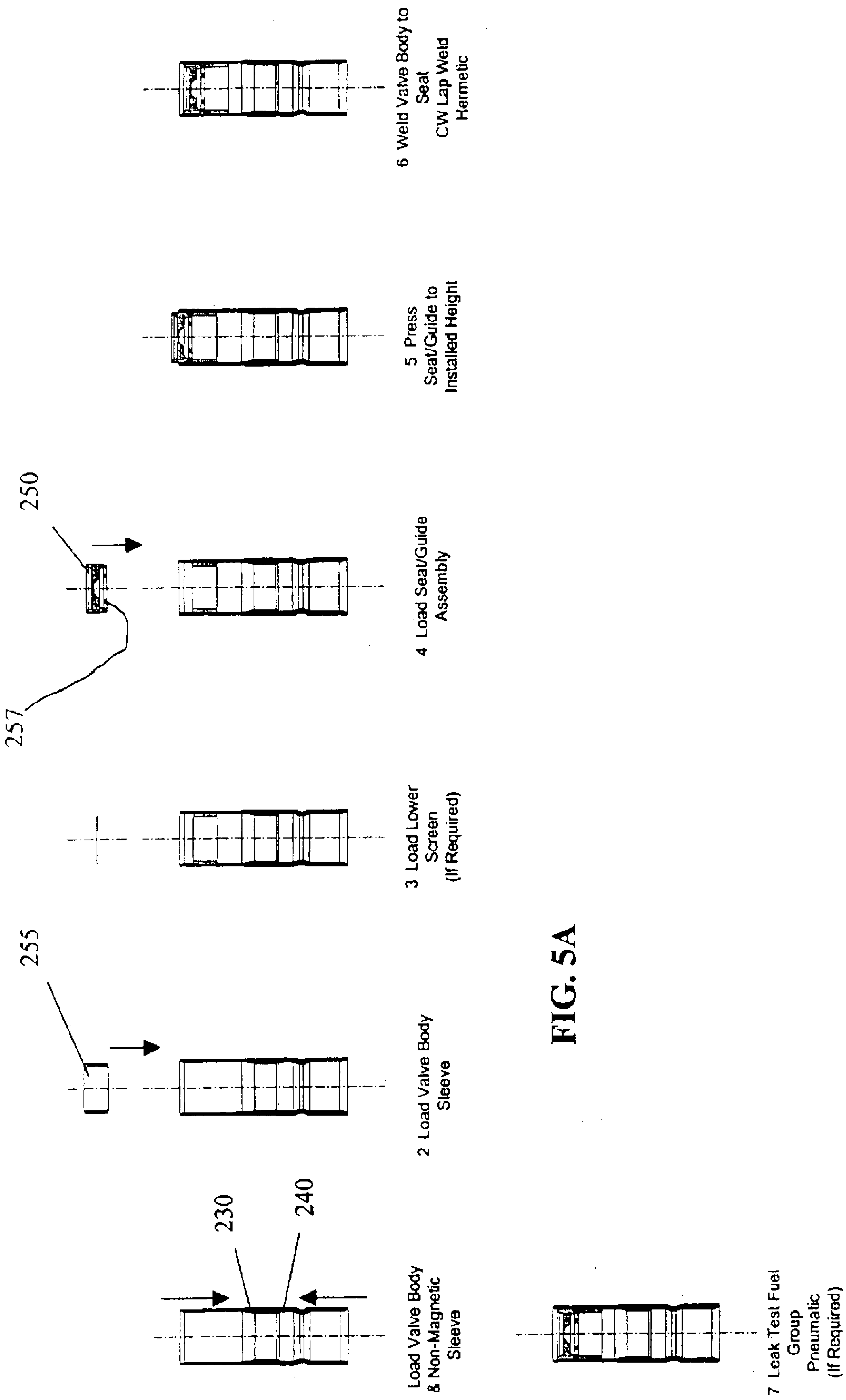

1 Load Valve Body & Non-Magnetic Sleeve
230
240
2 Load Valve Body Sleeve
255
3 Load Lower Screen (If Required)
4 Load Seat/Guide Assembly
250
257
5 Press Seat/Guide to Installed Height
6 Weld Valve Body to Seat CW Lap Weld Hermetic
7 Leak Test Fuel Group Pneumatic (If Required)

FIG. 5A

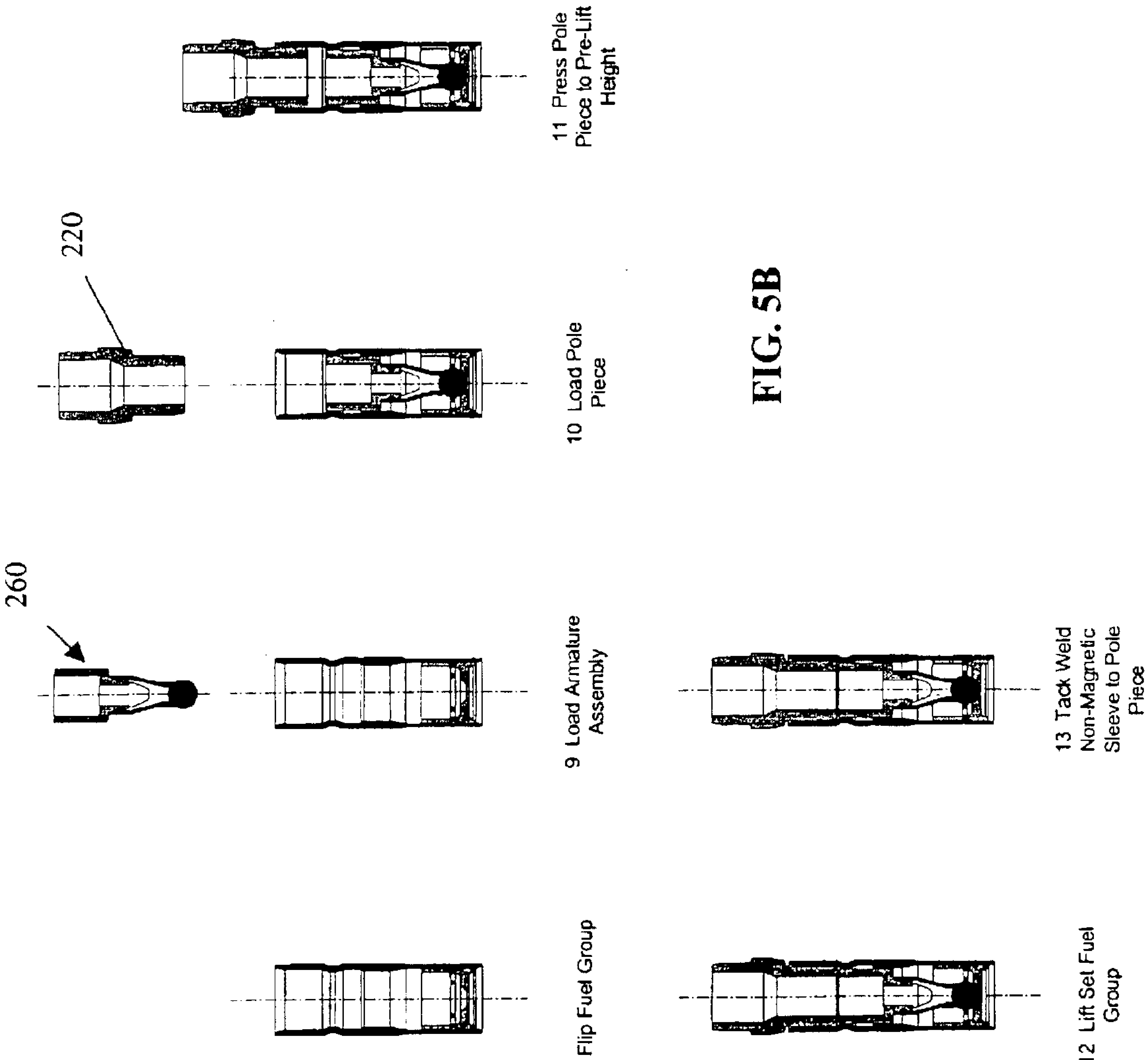

11 Press Pole Piece to Pre-Lift Height
220
10 Load Pole Piece
260
9 Load Armature Assembly
8 Flip Fuel Group
13 Tack Weld Non-Magnetic Sleeve to Pole Piece
12 Lift Set Fuel Group

FIG. 5B

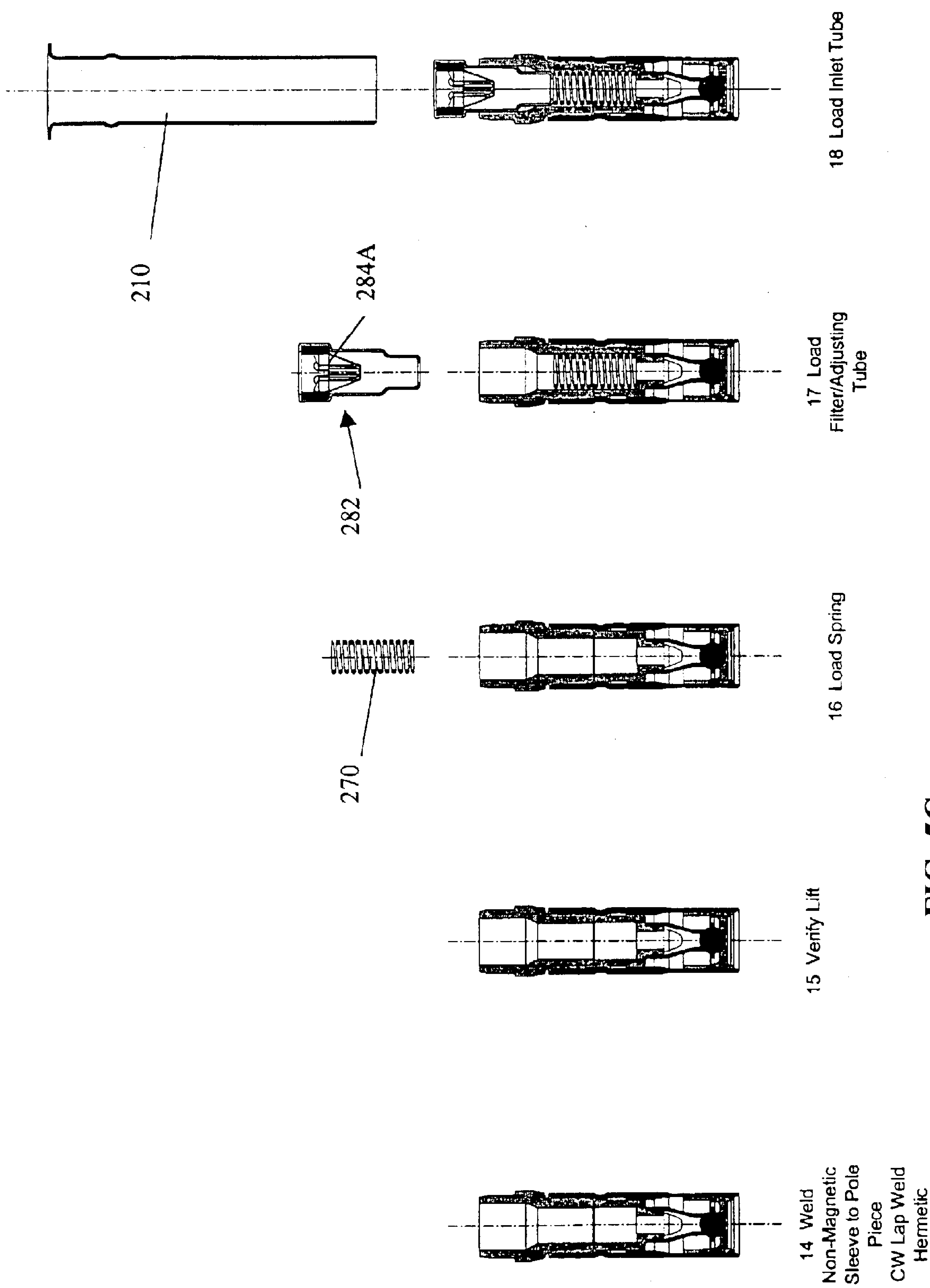

210
284A
282
270
18 Load Inlet Tube
17 Load Filter/Adjusting Tube
16 Load Spring
15 Verify Lift
14 Weld Non-Magnetic Sleeve to Pole Piece CW Lap Weld Hermetic

FIG. 5C

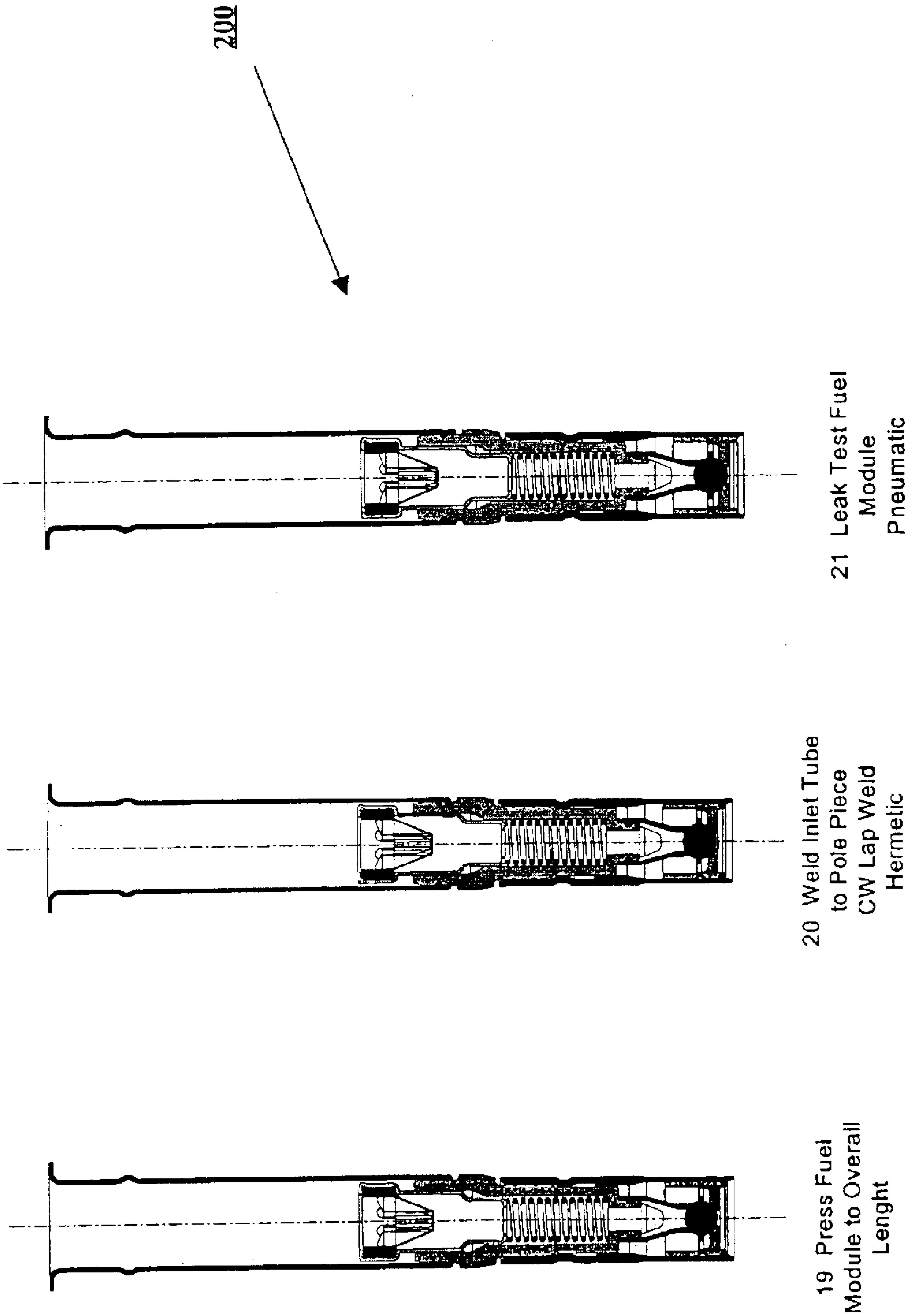
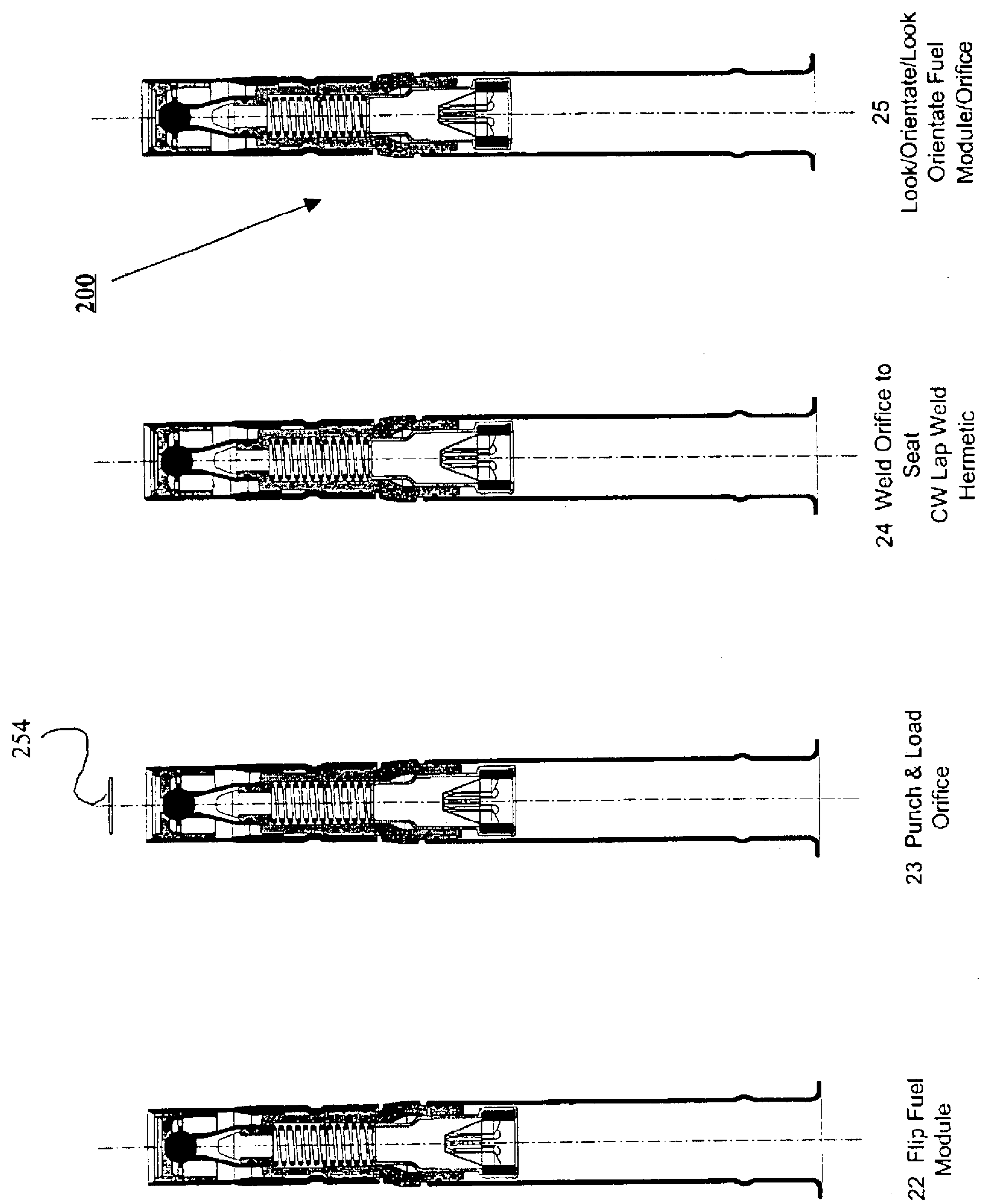

200
21 Leak Test Fuel Module Pneumatic
20 Weld Inlet Tube to Pole Piece CW Lap Weld Hermetic
19 Press Fuel Module to Overall Lenght

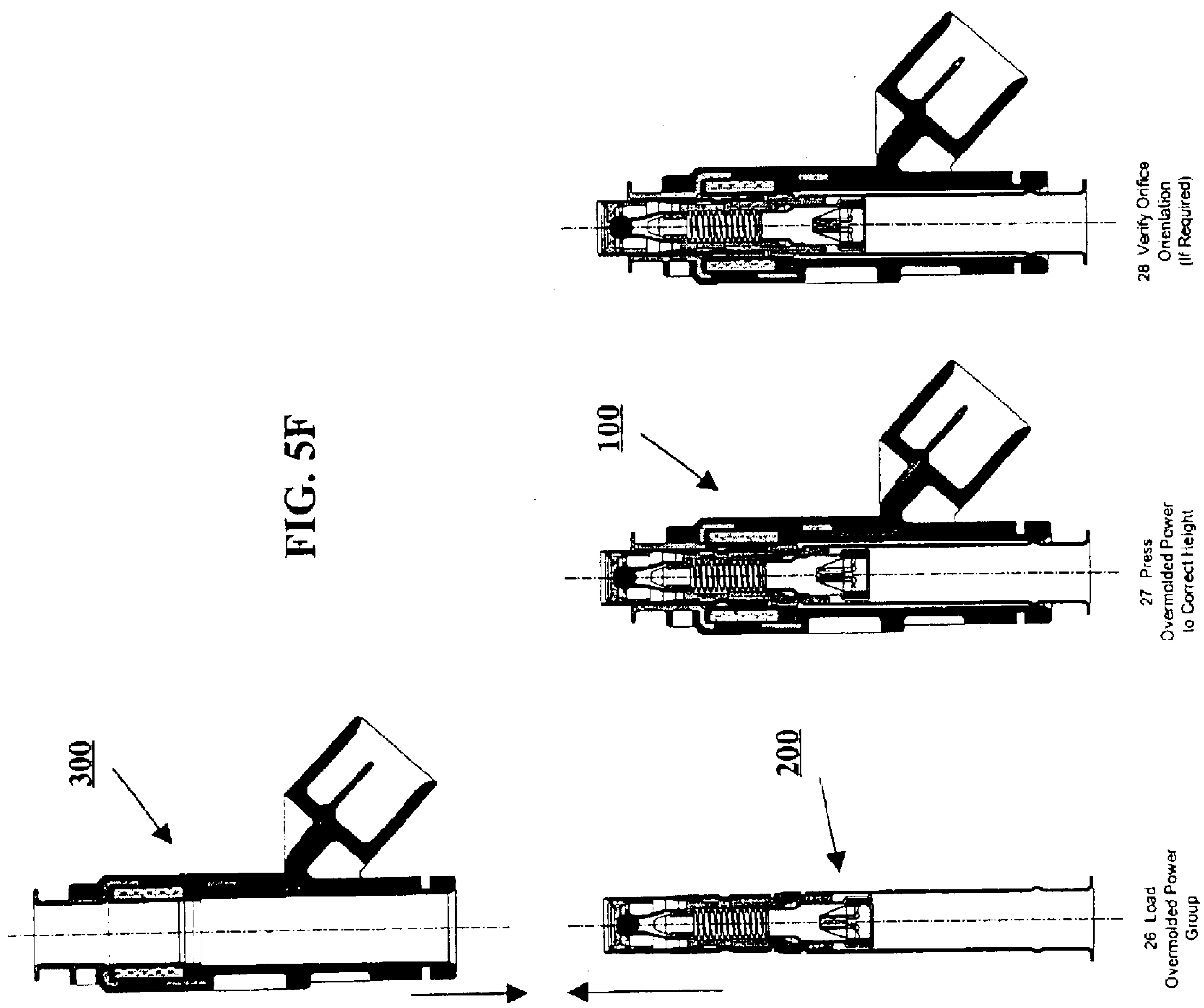
FIG. 5D



25
Look/Orientate/Look
Orientate Fuel
Module/Orifice
200
24 Weld Orifice to
Seat
CW Lap Weld
Hermetic
254
23 Punch & Load
Orifice
22 Flip Fuel
Module

FIG. 5E

FIG. 5F


300
100
200
26 Load
Overmolded Power
Group
27 Press
Overmolded Power
to Correct Height
28 Verify Orifice
Orientation
(If Required)

FUEL INJECTOR AND METHOD OF FORMING A HERMETIC SEAL FOR THE FUEL INJECTOR

This is a continuation of application application Ser. No. 09/828,487 filed on Apr. 9, 2001 now U.S. Pat. No. 6,676,044, the disclosures of which are hereby incorporated by reference herein in their entirety.

The present application is a continuation application filed pursuant to 35 U.S.C. §§120 and 121 and claims the benefits of prior application Ser. No. 09/828,487 filed Apr. 9, 2001, pending, which is hereby incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

It is believed that examples of known fuel injection systems use an injector to dispense a quantity of fuel that is to be combusted in an internal combustion engine. It is also believed that the quantity of fuel that is dispensed is varied in accordance with a number of engine parameters such as engine speed, engine load, engine emissions, etc.

It is believed that examples of known electronic fuel injection systems monitor at least one of the engine parameters and electrically operate the injector to dispense the fuel. It is believed that examples of known injectors use electromagnetic coils, piezoelectric elements, or magnetostrictive materials to actuate a valve.

It is believed that examples of known valves for injectors include a closure member that is movable with respect to a seat. Fuel flow through the injector is believed to be prohibited when the closure member sealingly contacts the seat, and fuel flow through the injector is believed to be permitted when the closure member is separated from the seat.

It is believed that examples of known injectors include a spring providing a force biasing the closure member toward the seat. It is also believed that this biasing force is adjustable in order to set the dynamic properties of the closure member movement with respect to the seat.

It is further believed that examples of known injectors include a filter for separating particles from the fuel flow, and include a seal at a connection of the injector to a fuel source.

It is believed that such examples of the known injectors have a number of disadvantages.

It is believed that examples of known injectors must be assembled entirely in an environment that is substantially free of contaminants. It is also believed that examples of known injectors can only be tested after final assembly has been completed.

SUMMARY OF THE INVENTION

According to the present invention, a fuel injector can comprise a plurality of modules, each of which can be independently assembled and tested. According to one embodiment of the present invention, the modules can comprise a fluid handling subassembly and an electrical subassembly. These subassemblies can be subsequently assembled to provide a fuel injector according to the present invention.

The present invention provides a fuel injector for use with an internal combustion engine. The fuel injector comprises a valve group subassembly and a coil group subassembly. The valve group subassembly includes a tube assembly having a longitudinal axis extending between a first end and a second end, the tube assembly including an inlet tube having an inlet tube face; a seat secured at the second end of the tube assembly, the seat defining an opening. An armature assembly disposed within the tube assembly, the armature assembly having a closure member disposed at one end of the armature assembly and an armature portion disposed at the other end of the armature assembly, the armature assembly having an armature face; a member biasing the armature assembly toward the seat. A filter assembly disposed within the tube assembly; an adjusting tube disposed within the tube assembly proximate the second end; a non-magnetic shell extending axially along the axis and coupled at one end of the shell to the inlet tube. A valve body coupled to the other end of the non-magnetic shell. A lift setting device disposed within the valve body. A valve seat disposed within the valve body and contiguously engaging the closure member; and a first attaching portion. The coil group subassembly includes a housing, a bobbin disposed partially within the housing, the bobbin having at least one contact portion formed thereon; a solenoid coil operable to displace the armature assembly with respect to the seat, the solenoid coil being electrically coupled to the contact terminals. At least one pre-bent terminal being electrically coupled to the contact portion; at least one overmold; and a second attaching portion fixedly connected to the first attaching portion.

The present invention also provides for a method of assembling a fuel injector. The method comprises providing a valve group subassembly and a coil group subassembly, inserting the valve group subassembly into the coil group subassembly, aligning the valve group subassembly relative to the coil group subassembly and affixing the two subassemblies. The valve group subassembly includes a tube assembly having a longitudinal axis extending between a first end and a second end, the tube assembly including an inlet tube having an inlet tube face; a seat secured at the second end of the tube assembly, the seat defining an opening; an armature assembly disposed within the tube assembly, the armature assembly having a closure member disposed at one end of the armature assembly and an armature portion disposed at the other end of the armature assembly, the armature assembly having an armature face; a member biasing the armature assembly toward the seat; a filter assembly disposed within the tube assembly; an adjusting tube disposed within the tube assembly proximate the second end; a non-magnetic shell extending axially along the axis and coupled at one end of the shell to the inlet tube; a valve body coupled to the other end of the non-magnetic shell; a lift setting device disposed within the valve body; a valve seat disposed within the valve body and contiguously engaging the closure member; and a first attaching portion. The coil group subassembly includes a housing; a bobbin disposed partially within the housing, the bobbin having at least one contact portion formed thereon; a solenoid coil operable to displace the armature assembly with respect to the seat, the solenoid coil being electrically coupled to the contact terminals; at least one pre-bent terminal electrically coupled to the contact portion; and at least one overmold.

The present invention also provides yet another method of assembling a modular fuel injector. The method comprises providing a valve group subassembly and a coil group subassembly, inserting the valve group subassembly into the coil group subassembly, aligning the valve group subassembly relative to the coil group subassembly and affixing the two subassemblies. The valve group subassembly includes a tube assembly having a longitudinal axis extending between a first end and a second end, the tube assembly including an inlet tube having an inlet tube face; a seat secured at the second end of the tube assembly, the seat defining an opening; an armature assembly disposed within the tube assembly, the armature assembly having a closure member disposed at one end of the armature assembly and an armature portion disposed at the other end of the armature assembly, the armature assembly having an armature face; a member biasing the armature assembly toward the seat; a filter assembly disposed within the tube assembly; an adjusting tube disposed within the tube assembly proximate the second end; a non-magnetic shell extending axially along the axis and coupled at one end of the shell to the inlet tube; a valve body coupled to the other end of the non-magnetic shell; a lift setting device disposed within the valve body; a valve seat disposed within the valve body and contiguously engaging the closure member; and a first attaching portion. The coil group subassembly includes a housing; a bobbin disposed partially within the housing, the bobbin having at least one contact portion formed thereon; a solenoid coil operable to displace the armature assembly with respect to the seat, the solenoid coil being electrically coupled to the contact terminals; at least one pre-bent terminal electrically coupled to the contact portion; and at least one overmold. The providing of the coil group or the power group further includes providing a clean room, fabricating the valve group in the clean room that comprises between 52 to 62 percent of a predetermined number of operations to assemble a ready-to-be shipped modular fuel injector, testing at least one of the valve group subassembly and coil group subassembly that comprises between 3 to 13 percent of the predetermined number of operations, performing welding operations on at least one of the valve group and coil group subassemblies that comprises between 3 to 8 percent of the predetermined number of operations, performing machine screw operations and machining operations on at least one of the valve group and the coil group subassemblies that comprise between 3 to 9 percent of the predetermined number of operations. At least one of the providing of the coil group subassembly and the assembling of the valve group and the coil group subassemblies can be performed, either inside or outside of the clean room, that comprises between 12 to 22 percent of the predetermined number of operations.

The present invention also provides method of manufacturing a fuel injector by providing a clean room, fabricating a fuel tube assembly, an armature assembly and fabricating a seat assembly in the clean room, assembling a fuel group by inserting an adjusting tube into the fuel tube assembly; inserting a biasing element into the fuel tube assembly; inserting the armature assembly into the fuel tube assembly; connecting the seat assembly to the fuel tube assembly; and inserting the fuel group into a power group outside the clean room.

The present invention further provides a method of assembling a fuel injector by providing a clean room, fabricating a fuel tube assembly, an armature assembly and a seat assembly in the clean room; assembling the fuel group by inserting an adjusting tube into the fuel tube assembly; inserting a biasing element into the fuel tube assembly; inserting the armature assembly into the fuel tube assembly; and connecting the seat assembly to the fuel tube assembly.

The present invention additionally provides for a method of manufacturing a modular fuel injector. The method comprises providing a clean room, manufacturing a sealed fuel injector unit via a predetermined number of operations by fabricating a fuel group in the clean room; testing the fuel injector including testing the fuel group and a power group; performing welding operations on at least one of the fuel group and power group; machining and performing screw

machine operations on at least one of the fuel group and power group; and assembling the fuel group with a power group outside the clean room into a sealed modular fuel injector unit. Each of the fabricating, testing, performing, machining and assembling operation comprises, respectively, a specified range of the predetermined number of operations.

The present invention provides yet another method of assembling a modular fuel injector. The method comprises providing a clean room, assembling a ready-to-deliver modular fuel injector unit by a predetermined number of assembling operations. The assembling operations include fabricating a fuel group in the clean room that comprises between 52 to 62 percent of the predetermined number of operations; testing the fuel injector including testing the fuel group and a power group that comprises between 3 to 13 percent of the predetermined number of operations; performing welding operations on at least one of the fuel group and power group that comprise between 3 to 8 percent of the predetermined number of operations; machining and performing machine screw operations on at least one of the fuel group and power group that comprise between 3 to 9 percent of the predetermined number of operations; and assembling the fuel group with a power group outside the clean room into a ready-to-deliver modular fuel injector unit that comprises between 12 to 22 percent of the predetermined number of operations.

The present invention further provides a method of setting armature lift in a fuel injector. The method comprises providing a tube assembly, providing a seat assembly having a seating surface, connecting the seat assembly to the second valve body end, and adjusting the distance between the first tube assembly end and the seating surface. The tube assembly includes an inlet tube assembly having a first tube assembly end; a non-magnetic shell having a first shell end and a second shell end, the first shell end being connected to the first tube assembly end; and a valve body having a first valve body end and a second valve body end, the first valve body end being connected to the second shell end.

The present invention additionally provides a method of connecting a fuel group to a power group. The method includes providing a fuel tube assembly having a longitudinal axis extending therethrough; installing an orifice plate on the fuel tube assembly, rotating the power group relative to the fuel group such that the at least one opening is disposed a predetermined angle from the power connector relative to the longitudinal axis; installing the fuel group in a power group; and fixedly connecting the fuel group to the power group. The orifice plate having at least one opening disposed away from the longitudinal axis. The power group includes a generally axially extending dielectric overmold and a power connector extending generally radially therefrom.

The present invention further provides a method of connecting a fuel group to a power group in a fuel injector. The method includes manufacturing a fuel group. The manufacturing includes providing a fuel tube assembly having a longitudinal axis extending therethrough; installing an orifice plate on the fuel tube assembly, the orifice plate having at least one opening disposed away from the longitudinal axis. The method further comprises providing a power group having a generally axially extending dielectric overmold and a power connector extending generally radially therefrom; rotating the power group relative to the fuel group such that the at least one opening is disposed a predetermined angle from the power connector relative to the longitudinal axis. After the power group is rotated, installing the fuel group in the power group, and fixedly connecting the fuel group to the power group.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated herein and constitute part of this specification, illustrate an embodiment of the invention, and, together with the general description given above and the detailed description given below, serve to explain features of the invention.

FIG. **1** is a cross-sectional view of a fuel injector according to the present invention.

FIG. **1**A is a cross-sectional view of a variation on the filter assembly of the fuel injector according to the present invention.

FIG. **2** is a cross-sectional view of a fluid handling subassembly of the fuel injector shown in FIG. **1**.

FIG. **2**A is a cross-sectional view of a variation of the fuel filter in the fluid handling subassembly of the fuel injector shown in FIG. **2**.

FIGS. **2**B–**2**D are cross-sectional views of views of various inlet tube assemblies usable in the fuel injector.

FIGS. **2**E and **2**F are close-up views of the surface treatments for the impact surfaces of the electromagnetic actuator of the fuel injector.

FIGS. **2**G–**2**I are cross-sectional views of various armature assemblies usable with the fuel injector.

FIGS. **2**J–**2**L are cross-sectional views of various valve closure members usable with the fuel injector.

FIG. **2**M illustrates one preferred embodiment to retain the orifice plate and the sealing member at an outlet end of the fuel injector.

FIGS. **2**N and **2**O are exploded views of how an injector lift can be set for the fuel injector.

FIG. **3** is a cross-sectional view of an electrical subassembly of the fuel injector shown in FIG. **1**.

FIG. **3**A is a cross-sectional view of the two-piece overmold instead of the one-piece overmold of the electrical subassembly of FIG. **3**.

FIG. **3**B is an exploded view of the electrical subassembly of the fuel injector of FIG. **1**.

FIG. **4** is an isometric view that illustrates assembling the fluid handling and electrical subassemblies that are shown in FIGS. **2** and **3**, respectively.

FIGS. **4**A and **4**B are close-up views of the high efficiency magnetic assembly as utilized in the fuel injector.

FIG. **5** is a flow chart of the method of assembling the modular fuel injector according to the present invention.

FIGS. **5**A–**5**F are detailed illustrations of the method summarized in FIG. **5**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. **1**–**4**, a solenoid actuated fuel injector **100** dispenses a quantity of fuel that is to be combusted in an internal combustion engine (not shown). The fuel injector **100** extends along a longitudinal axis between a first injector end **238** and a second injector end **239**, and includes a valve group subassembly **200** and a power group subassembly **300**. The valve group subassembly **200** performs fluid handling functions, e.g., defining a fuel flow path and prohibiting fuel flow through the injector **100**. The power group subassembly **300** performs electrical functions, e.g., converting electrical signals to a driving force for permitting fuel flow through the injector **100**.

Referring to FIGS. **1** and **2**, the valve group subassembly **200** comprises a tube assembly extending along the longitudinal axis A—A between a first tube assembly end **200**A and a second tube assembly end **200**B. The tube assembly includes at least an inlet tube, a non-magnetic shell **230**, and a valve body. The inlet tube has a first inlet tube end proximate to the first tube assembly end **200**A. A second inlet tube end of the inlet tube is connected to a first shell end of the non-magnetic shell **230**. A second shell end of the non-magnetic shell **230** is connected to a first valve body end of the valve body. A second valve body end of the valve body **240** is disposed proximate to the second tube assembly end **200**B. The inlet tube can be formed by a deep drawing process or by a rolling operation. A pole piece can be integrally formed at the second inlet tube end of the inlet tube or, as shown, a separate pole piece **220** can be connected to a partial inlet tube and connected to the first shell end of the non-magnetic shell **230**. The non-magnetic shell **230** can comprise non-magnetic stainless steel, e.g., 300 series stainless steels, or other materials that have similar structural and magnetic properties.

As shown in FIG. **2**, inlet tube **210** is attached to pole piece **220** by means of welds. Formed into the outer surface of pole piece **220** are shoulders **222**A, which, in conjunction with shoulders **222**B of the coil subassembly, act as positive mounting stops when the injector is assembled. As shown in FIGS. **2**C and **2**D, the length of pole piece is fixed whereas the length of inlet tube can vary according to operating requirements. By forming inlet tube **210** separately from pole piece **220**, different length injectors can be manufactured by using different inlet tube lengths during the assembly process. Inlet tube **220** can be flared at the inlet end to retain the O-ring **290**.

Referring again to FIG. **2**, the inlet tube **210** can be attached to the pole piece **220** at an inner circumferential surface of the pole piece **220**. Alternatively, as shown in FIG. **2**B, an integral inlet tube and pole piece assembly **211** can be attached to the inner circumferential surface of the non-magnetic shell **230**.

An armature assembly **260** is disposed in the tube assembly. The armature assembly **260** includes a first armature assembly end having a ferro-magnetic or armature portion **262** and a second armature assembly end having a sealing portion. The armature assembly **260** is disposed in the tube assembly such that the magnetic portion, or "armature," **262** confronts the pole piece **220**. The sealing portion can include a closure member **264**, e.g., a spherical valve element, that is moveable with respect to the seat **250** and its sealing surface **252**. The closure member **264** is movable between a closed configuration, as shown in FIGS. **1** and **2**, and an open configuration (not shown). In the closed configuration, the closure member **264** contiguously engages the sealing surface **252** to prevent fluid flow through the opening. In the open configuration, the closure member **264** is spaced from the seat **250** to permit fluid flow through the opening. The armature assembly **260** may also include a separate intermediate portion **266** connecting the ferro-magnetic or armature portion **262** to the closure member **264**. The intermediate portion or armature tube **266** can be fabricated by various techniques, for example, a plate can be rolled and its seams welded or a blank can be deep-drawn to form a seamless tube. The intermediate portion **266** is preferable due to its ability to reduce magnetic flux leakage from the magnetic circuit of the fuel injector **100**. This ability arises from the fact that the intermediate portion or armature tube **266** can be non-magnetic, thereby magnetically decoupling the magnetic portion or armature **262** from the ferro-magnetic closure member **264**. Because the ferro-magnetic closure member is decoupled from the ferro-magnetic or armature **262**, flux leakage is reduced, thereby improving the efficiency of the magnetic circuit.

Surface treatments can be applied to at least one of the end portions **221** and **261** to improve the armature's response, reduce wear on the impact surfaces and variations in the working air gap between the respective end portions **221** and **261**. The surface treatments can include coating, plating or case-hardening. Coatings or platings can include, but are not limited to, hard chromium plating, nickel plating or keronite coating. Case hardening on the other hand, can include, but are not limited to, nitriding, carburizing, carbonitriding, cyaniding, heat, flame, spark or induction hardening.

The surface treatments will typically form at least one layer of wear-resistant materials **261A** or **221A** on the respective end portions. This layers, however, tend to be inherently thicker wherever there is a sharp edge, such as between junction between the circumference and the radial end face of either portions. Moreover, this thickening effect results in uneven contact surfaces at the radially outer edge of the end portions. However, by forming the wear-resistant layers on at least one of the end portions **221** and **261**, where at least one end portion has a surface **263** generally oblique to longitudinal axis A—A, both end portions are now substantially in mating contact with respect to each other.

As shown in FIG. **2E**, the end portions **221** and **261** are generally symmetrical about the longitudinal axis A—A. As further shown in FIG. **2F**, the surface **263** of at least one of the end portions can be of a general conic, frustoconical, spheroidal or a surface generally oblique with respect to the axis A—A.

Since the surface treatments may affect the physical and magnetic properties of the ferromagnetic portion of the armature assembly **260** or the pole piece **220**, a suitable material, e.g., a mask, a coating or a protective cover, surrounds areas other than the respective end portions **221** and **261** during the surface treatments. Upon completion of the surface treatments, the material is removed, thereby leaving the previously masked areas unaffected by the surface treatments.

Fuel flow through the armature assembly **260** can be provided by at least one axially extending through-bore **267** and at least one apertures **268** through a wall of the armature assembly **260**. The apertures **268**, which can be of any shape, are preferably non-circular, e.g., axially elongated, to facilitate the passage of gas bubbles. For example, in the case of a separate intermediate portion **266** that is formed by rolling a sheet substantially into a tube, the apertures **268** can be an axially extending slit defined between non-abutting edges of the rolled sheet. However, the apertures **268**, in addition to the slit, would preferably include openings extending through the sheet. The apertures **268** provide fluid communication between the at least one through-bore **267** and the interior of the valve body. Thus, in the open configuration, fuel can be communicated from the through-bore **267**, through the apertures **268** and the interior of the valve body, around the closure member, and through the opening into the engine (not shown).

To permit the use of extended tip injectors, FIG. **2G** shows a three-piece armature **260** comprising the armature tube **266**, elongated openings **268** and the closure member **264**. One example of an extended tip three-piece armature is shown as armature assembly **260A** in FIG. **2H**. The extended tip armature assembly **260A** includes elongated apertures **269** to facilitate the passage of trapped fuel vapor. As a further alternative, a two-piece armature **260B**, shown here in FIG. **2I**, can be utilized with the present invention. Although both the three-piece and the two-piece armature assemblies are interchangeable, the three-piece armature assembly **266** or **266A** is preferable due to its ability to reduce magnetic flux leakage from the magnetic circuit of the fuel injector **100** according to the present invention. This ability arises from the fact that the armature tube **266** or **266A** can be non-magnetic, thereby magnetically decoupling the magnetic portion or armature **262** from the ferro-magnetic closure member **264**. Because the ferro-magnetic closure member is decoupled from the ferro-magnetic or armature portion **262**, flux leakage is reduced, thereby improving the efficiency of the magnetic circuit. Furthermore, the three-piece armature assembly can be fabricated with fewer machining processes as compared to the two-piece armature assembly. It should be noted that the armature tube **266** or **266A** of the three-piece armature assembly can be fabricated by various techniques, for example, a plate can be rolled and its seams welded or a blank can be deep-drawn to form a seamless tube.

The elongated openings **269** and apertures **268** in the three-piece extended tip armature **260A** serve two related purposes. First, the elongated openings **269** and apertures **268** allow fuel to flow out of the armature tube **266A**. Second, elongated openings **269** allows hot fuel vapor in the armature tube **266A** to vent into the valve body **240** instead of being trapped in the armature tube **266A**, and also allows pressurized liquid fuel to displace any remaining fuel vapor trapped therein during a hot start condition.

A seat **250** is secured at the second end of the tube assembly. The seat **250** defines an opening centered on the axis A—A and through which fuel can flow into the internal combustion engine (not shown). The seat **250** includes a sealing surface **252** surrounding the opening. The sealing surface, which faces the interior of the valve body **240**, can be frustoconical or concave in shape, and can have a finished surface. An orifice disk **254** can be used in connection with the seat **250** to provide at least one precisely sized and oriented orifice **254A** in order to obtain a particular fuel spray pattern. The precisely sized and oriented orifice **254A** can be disposed on the center axis of the orifice plate **254** as shown in FIG. **2N** or, preferably, an orifice **254B** can disposed off-axis, shown in FIG. **2O**, and oriented in any desirable angular configuration relative to one or more reference points on the fuel injector **100**. It should be noted here that both the valve seat **250** and orifice plate are fixedly attached to the valve body by known conventional attachment techniques, including, for example, laser welding, crimping, and friction welding or conventional welding. Alternatively, a cap-shaped retainer **258** as shown in FIG. **2M** can retain the orifice plate **254** on the valve body **240**.

As shown in FIG. **2J**, the orifice plate **254** is attached to the valve seat **250**, which valve seat **250** is attached to the valve body **240**. To ensure a positive seal, closure member **264** is attached to intermediate portion **266** by welds and is biased by resilient member **270** towards a closed position. To achieve different spray patterns or to ensure a large volume of fuel injected relative to a low injector lift height, it is contemplated that the spherical closure member **264** be in the form of a flat-faced ball, shown enlarged in detail in FIGS. **2K** and **2L**. Welds **261** can be internally formed between the junction of the intermediate portion **266** and the closure member **264** to the intermediate portion **266**, respectively. Valve seat **250** can be attached to valve body **240** in two different ways. As shown in FIG. **2K**, valve seat **250** may simply be floatingly mounted between valve body **240** and orifice plate **254** with an O-ring **251** to prevent fuel leakage around valve seat **250**. Here, the orifice plate **254** can be retained by crimps **240**A that can be formed on the valve body **240**. Alternatively, valve seat **250** may simply be affixed by at least a weld **251**A to valve body **240** as shown in FIG. **2**L while the orifice plate **254** can be welded to the seat **250**.

In the case of a spherical valve element providing the closure member, the spherical valve element can be connected to the armature assembly **260** at a diameter that is less than the diameter of the spherical valve element. Such a connection would be on side of the spherical valve element that is opposite contiguous contact with the seat **250**. A lower armature guide can be disposed in the tube assembly, proximate the seat **250**, and would slidingly engage the diameter of the spherical valve element. The lower armature guide can facilitate alignment of the armature assembly **260** along the axis A—A.

Referring back to the retainer **258**, shown enlarged in FIG. **2**M, the retainer includes finger-like locking portions **259**B allowing the retainer **258** to be snap-fitted on a complementarily grooved portion **259**A of the valve body **240**. Retainer **258** is further retained on the valve body **240** by resilient locking, finger-like portions **259**, which are received, by complementary grooved portions **259**A on the valve body **240**. To retain the orifice disk **254** flush against the valve seat **250**, a dimpled or recessed portion **259**C is formed on the radial face of the retainer **258** to receive the orifice disk **254**. To ensure that the retainer **258** is imbued with sufficient resiliency, the thickness of the retainer **258** should be at most one-half the thickness of the valve body. A flared-portion **259**D of the retainer **258** also supports the sealing o-ring **290**. The use of resilient retainer **258** obviates the need for welding the orifice disk **254** to the valve seat **250** while also functioning as an o-ring support.

A resilient member **270** is disposed in the tube assembly and biases the armature assembly **260** toward the seat **250**. A filter assembly **282** comprising a filter **284**A and an integral retaining portion **283** is also disposed in the tube assembly. The filter assembly **282** includes a first end and a second end. The filter **284**A is disposed at one end of the filter assembly **282** and also located proximate to the first end of the tube assembly and apart from the resilient member **270** while the adjusting tube **281** is disposed generally proximate to the second end of the tube assembly. The adjusting tube **281** engages the resilient member **270** and adjusts the biasing force of the member with respect to the tube assembly. In particular, the adjusting tube **281** provides a reaction member against which the resilient member **270** reacts in order to close the injector valve **100** when the power group subassembly **300** is de-energized. The position of the adjusting tube **281** can be retained with respect to the inlet tube **210** by an interference fit between an outer surface of the adjusting tube **281** and an inner surface of the tube assembly. Thus, the position of the adjusting tube **281** with respect to the inlet tube **210** can be used to set a predetermined dynamic characteristic of the armature assembly **260**.

The filter assembly **282** includes a cup-shaped filtering element **284**A and an integral-retaining portion **283** for positioning an O-ring **290** proximate the first end of the tube assembly. The O-ring **290** circumscribes the first end of the tube assembly and provides a seal at a connection of the injector **100** to a fuel source (not shown). The retaining portion **283** retains the O-ring **290** and the filter element with respect to the tube assembly.

Two variations on the fuel filter of FIG. **1** are shown in FIGS. **1**A and **2**A. In FIG. **1**A, a fuel filter assembly **282**' with filter **285** is attached to the adjusting tube **280**'. Likewise, in FIG. **2**A, the filter assembly **282**" includes an inverted-cup filtering element **284**B attached to an adjusting tube **280**". Similar to adjusting tube **281** described above, the adjusting tube **280**' or **280**" of the respective fuel filter assembly **282**' or **282**" engages the resilient member **270** and adjusts the biasing force of the member with respect to the tube assembly. In particular, the adjusting tube **280**' or **280**" provides a reaction member against which the resilient member **270** reacts in order to close the injector valve **100** when the power group subassembly **300** is de-energized. The position of the adjusting tube **280**' or **280**" can be retained with respect to the inlet tube **210** by an interference fit between an outer surface of the adjusting tube **280**' or **280**" and an inner surface of the tube assembly.

The valve group subassembly **200** can be assembled as follows. The non-magnetic shell **230** is connected to the inlet tube **210** and to the valve body. The adjusting tube **280**A or the filter assembly **282**' or **282**" is inserted along the axis A—A from the first end **200**A of the tube assembly. Next, the resilient member **270** and the armature assembly **260** (which was previously assembled) are inserted along the axis A—A from the injector end **239** of the valve body **240**. The adjusting tube **280**A, the filter assembly **282**' or **282**" can be inserted into the inlet tube **210** to a predetermined distance so as to permit the adjusting tube **280**A, **280**B or **280**C to preload the resilient member **270**. Positioning of the filter assembly **282**, and hence the adjusting tube **280**B or **280**C with respect to the inlet tube **210** can be used to adjust the dynamic properties of the resilient member **270**, e.g., so as to ensure that the armature assembly **260** does not float or bounce during injection pulses. The seat **250** and orifice disk **254** are then inserted along the axis A—A from the second valve body end of the valve body. The seat **250** and orifice disk **254** can be fixedly attached to one another or to the valve body by known attachment techniques such as laser welding, crimping, friction welding, conventional welding, etc.

Referring to FIGS. **1** and **3**, the power group subassembly **300** comprises an electromagnetic coil **310**, at least one terminal **320**, a housing **330**, and an overmold **340**. The electromagnetic coil **310** comprises a wire **312** that that can be wound on a bobbin **314** and electrically connected to electrical contacts on the bobbin **314**. When energized, the coil generates magnetic flux that moves the armature assembly **260** toward the open configuration, thereby allowing the fuel to flow through the opening. De-energizing the electromagnetic coil **310** allows the resilient member **270** to return the armature assembly **260** to the closed configuration, thereby shutting off the fuel flow. The housing, which provides a return path for the magnetic flux, generally comprises a ferro-magnetic cylinder **332** surrounding the electromagnetic coil **310** and a flux washer **334** extending from the cylinder toward the axis A—A. The washer **334** can be integrally formed with or separately attached to the cylinder. The housing **330** can include holes, slots, or other features to break-up eddy currents that can occur when the coil is energized.

The overmold **340** maintains the relative orientation and position of the electromagnetic coil **310**, the at least one terminal (two are used in the illustrated example), and the housing. The overmold **340** includes an electrical harness connector **321** portion in which a portion of the terminal **320** is exposed. The terminal **320** and the electrical harness connector **321** portion can engage a mating connector, e.g., part of a vehicle wiring harness (not shown), to facilitate connecting the injector **100** to an electrical power supply (not shown) for energizing the electromagnetic coil **310**.

According to a preferred embodiment, the magnetic flux generated by the electromagnetic coil **310** flows in a circuit that comprises, the pole piece **220**, the armature assembly **260**, the valve body **240**, the housing **330**, and the flux washer **334**. As seen in FIGS. **4**A and **4**B, the magnetic flux moves across a parasitic airgap between the homogeneous material of the magnetic portion or armature **262** and the valve body **240** into the armature assembly **260** and across the working air gap towards the pole piece **220**, thereby lifting the closure member **264** off the seat **250**. As can further be seen in FIG. **4**B, the width "a" of the impact surface of pole piece **220** is greater than the width "b" of the cross-section of the impact surface of magnetic portion or armature **262**. The smaller cross-sectional area "b" allows the ferro-magnetic portion **262** of the armature assembly **260** to be lighter, and at the same time, causes the magnetic flux saturation point to be formed near the working air gap between the pole piece **220** and the ferro-magnetic portion **262**, rather than within the pole piece **220**. Furthermore, since the armature **262** is partly within the interior of the electromagnetic coil **310**, the magnetic flux is denser, leading to a more efficient electromagnetic coil. Finally, because the ferro-magnetic closure member **264** is magnetically decoupled from the ferro-magnetic or armature portion **262** via the armature tube **266**, flux leakage of the magnetic circuit is reduced, thereby improving the efficiency of the electromagnetic coil **310**.

The coil group subassembly **300** can be constructed as follows. A plastic bobbin **314** can be molded with at least one electrical contacts **322**. The wire **312** for the electromagnetic coil **310** is wound around the plastic bobbin **314** and connected to the electrical contacts **322**. The housing **330** is then placed over the electromagnetic coil **310** and bobbin **314**. A terminal **320**, which is pre-bent to a proper shape, is then electrically connected to each electrical contact **322**. An overmold **340** is then formed to maintain the relative assembly of the coil/bobbin unit, housing **330**, and terminal **320**. The overmold **340** also provides a structural case for the injector and provides predetermined electrical and thermal insulating properties. A separate collar can be connected, e.g., by bonding, and can provide an application specific characteristic such as an orientation feature or an identification feature for the injector **100**. Thus, the overmold **340** provides a universal arrangement that can be modified with the addition of a suitable collar. To reduce manufacturing and inventory costs, the coil/bobbin unit can be the same for different applications. As such, the terminal **320** and overmold **340** (or collar, if used) can be varied in size and shape to suit particular tube assembly lengths, mounting configurations, electrical connectors, etc.

Alternatively, as shown in FIG. **3**A, a two-piece overmold allows for a first overmold **341** that is application specific while the second overmold **342** can be for all applications. The first overmold **341** is bonded to a second overmold **342**, allowing both to act as electrical and thermal insulators for the injector. Additionally, a portion of the housing **330** can extend axially beyond an end of the overmold **340** to allow the injector to accommodate different length injector tips. The extended portion also can be formed with a flange to retain an O-ring.

As is particularly shown in FIGS. **1** and **4**, the valve group subassembly **200** can be inserted into the coil group subassembly **300**. Thus, the injector **100** is made of two modular subassemblies that can be assembled and tested separately, and then connected together to form the injector **100**. The valve group subassembly **200** and the coil group subassembly **300** can be fixedly attached by adhesive, welding, or another equivalent attachment process. According to a preferred embodiment, a hole **360** through the overmold **340** exposes the housing **330** and provides access for laser welding the housing **330** to the valve body. The filter and the retainer, which may be an integral unit, can be connected to the first tube assembly end **200**A of the tube unit. The O-rings can be mounted at the respective first and second injector ends.

The first injector end **238** can be coupled to the fuel supply of an internal combustion engine (not shown). The O-ring **290** can be used to seal the first injector end **238** to the fuel supply so that fuel from a fuel rail (not shown) is supplied to the tube assembly, with the O-ring **290** making a fluid tight seal, at the connection between the injector **100** and the fuel rail (not shown).

In operation, the electromagnetic coil **310** is energized, thereby generating magnetic flux in the magnetic circuit. The magnetic flux moves armature assembly **260** (along the axis A—A, according to a preferred embodiment) towards the integral pole piece **220**, i.e., closing the working air gap. This movement of the armature assembly **260** separates the closure member **264** from the seat **250** and allows fuel to flow from the fuel rail (not shown), through the inlet tube **210**, the through-bore **267**, the apertures **268** and the valve body, between the seat **250** and the closure member, through the opening, and finally through the orifice disk **254** into the internal combustion engine (not shown). When the electromagnetic coil **310** is de-energized, the armature assembly **260** is moved by the bias of the resilient member **270** to contiguously engage the closure member **265** with the seat **250**, and thereby prevent fuel flow through the injector **100**.

Referring to FIG. **5**, a preferred assembly process can be as follows:

1. A pre-assembled valve body and non-magnetic sleeve is located with the valve body oriented up.
2. A screen retainer, e.g., a lift sleeve, is loaded into the valve body/non-magnetic sleeve assembly.
3. A lower screen can be loaded into the valve body/non-magnetic sleeve assembly.
4. A pre-assembled seat and guide assembly is loaded into the valve body/non-magnetic sleeve assembly.
5. The seat/guide assembly is pressed to a desired position within the valve body/non-magnetic sleeve assembly.
6. The valve body is welded, e.g., by a continuous wave laser forming a hermetic lap seal, to the seat.
7. A first leak test is performed on the valve body/non-magnetic sleeve assembly. This test can be performed pneumatically.
8. The valve body/non-magnetic sleeve assembly is inverted so that the non-magnetic sleeve is oriented up.
9. An armature assembly is loaded into the valve body/non-magnetic sleeve assembly.
10. A pole piece is loaded into the valve body/non-magnetic sleeve assembly and pressed to a pre-lift position.
11. Dynamically, e.g., pneumatically, purge valve body/non-magnetic sleeve assembly.
12. Set lift.
13. The non-magnetic sleeve is welded, e.g., with a tack weld, to the pole piece.
14. The non-magnetic sleeve is welded, e.g., by a continuous wave laser forming a hermetic lap seal, to the pole piece.

15. Verify lift
16. A spring is loaded into the valve body/non-magnetic sleeve assembly.
17. A filter/adjusting tube is loaded into the valve body/non-magnetic sleeve assembly and pressed to a pre-cal position.
18. An inlet tube is connected to the valve body/non-magnetic sleeve assembly to generally establish the fuel group subassembly.
19. Axially press the fuel group subassembly to the desired over-all length.
20. The inlet tube is welded, e.g., by a continuous wave laser forming a hermetic lap seal, to the pole piece.
21. A second leak test is performed on the fuel group subassembly. This test can be performed pneumatically.
22. The fuel group subassembly is inverted so that the seat is oriented up.
23. An orifice is punched and loaded on the seat.
24. The orifice is welded, e.g., by a continuous wave laser forming a hermetic lap seal, to the seat.
25. The rotational orientation of the fuel group subassembly/orifice can be established with a "look/orient/look" procedure using reference points on the valve body subassembly and the coil group subassembly. For example, a computer equipped with machine vision can locate a reference point on the orifice plate of the fuel group and a reference point on the fuel group subassembly. The computer then rotate at least one or both of the fuel group and the power group as a function of a calculated angular difference between the two reference points. Subsequently, the two subassemblies are inserted or press-fitted into each other.
26. The fuel group subassembly is inserted into the (pre-assembled) power group subassembly.
27. The power group subassembly is pressed to a desired axial position with respect to the fuel group subassembly.
28. The rotational orientation of the fuel group subassembly/orifice/power group subassembly can be verified.
29. The power group subassembly can be laser marked with information such as part number, serial number, performance data, a logo, etc.
30. Perform a high-potential electrical test.
31. The housing of the power group subassembly is tack welded to the valve body.
32. A lower O-ring can be installed. Alternatively, this lower O-ring can be installed as a post test operation.
33. An upper O-ring is installed.
34. Invert the fully assembled fuel injector.
35. Transfer the injector to a test rig.

To set the lift, i.e., ensure the proper injector lift distance, there are at least four different techniques that can be utilized. According to a first technique, a crush ring or a washer that is inserted into the valve body **240** between the lower guide **257** and the valve body **240** can be deformed. According to a second technique, the relative axial position of the valve body **240** and the non-magnetic shell **230** can be adjusted before the two parts are affixed together. According to a third technique, the relative axial position of the non-magnetic shell **230** and the pole piece **220** can be adjusted before the two parts are affixed together. And according to a fourth technique, a lift sleeve **255** can be displaced axially within the valve body **240**. If the lift sleeve technique is used, the position of the lift sleeve can be adjusted by moving the lift sleeve axially. The lift distance can be measured with a test probe. Once the lift is correct, the sleeve is welded to the valve body **240**, e.g., by laser welding. Next, the valve body **240** is attached to the inlet tube **210** assembly by a weld, preferably a laser weld. The assembled fuel group subassembly **200** is then tested, e.g., for leakage.

As is shown in FIG. **5**, the lift set procedure may not be able to progress at the same rate as the other procedures. Thus, a single production line can be split into a plurality (two are shown) of parallel lift setting stations, which can thereafter be recombined back into a single production line.

The preparation of the power group sub-assembly, which can include (a) the housing **330**, (b) the bobbin assembly including the terminals **320**, (c) the flux washer **334**, and (d) the overmold **340**, can be performed separately from the fuel group subassembly.

According to a preferred embodiment, wire **312** is wound onto a pre-formed bobbin **314** having electrical connector portions **322**. The bobbin assembly is inserted into a pre-formed housing **330**, shown here in FIG. **3**B. To provide a return path for the magnetic flux between the pole piece **220** and the housing **330**, flux washer **334** is mounted on the bobbin assembly. A pre-bent terminal **320** having axially extending connector portions **324** are coupled to the electrical contact portions **322** and brazed, soldered welded, or, preferably, resistance welded. The partially assembled power group assembly is now placed into a mold (not shown). By virtue of its pre-bent shape, the terminals **320** will be positioned in the proper orientation with the harness connector **321** when a polymer is poured or injected into the mold. Alternatively, two separate molds (not shown) can be used to form a two-piece overmold as described with respect to FIG. **3**A. The assembled power group subassembly **300** can be mounted on a test stand to determine the solenoid's pull force, coil resistance and the drop in voltage as the solenoid is saturated.

The inserting of the fuel group subassembly **200** into the power group subassembly **300** operation can involve setting the relative rotational orientation of fuel group subassembly **200** with respect to the power group subassembly **300**. According to the preferred embodiments, the fuel group and the power group subassemblies can be rotated such that the included angle between the reference point(s) on the orifice plate **254** (including opening(s) thereon) and a reference point on the injector harness connector **321** are within a predetermined angle. The relative orientation can be set using robotic cameras or computerized imaging devices to look at respective predetermined reference points on the subassemblies, calculate the angular rotation necessary for alignment, orientating the subassemblies and then checking with another look and so on until the subassemblies are properly orientated. Once the desired orientation is achieved, the subassemblies are inserted together. The inserting operation can be accomplished by one of two methods: "top-down" or "bottom-up." According to the former, the power group subassembly **300** is slid downward from the top of the fuel group subassembly **200**, and according to the latter, the power group subassembly **300** is slid upward from the bottom of the fuel group subassembly **200**. In situations where the inlet tube **210** assembly includes a flared first end, bottom-up method is required. Also in these situations, the O-ring **290** that is retained by the flared first end can be positioned around the power group subassembly **300** prior to sliding the fuel group subassembly **200** into the power group subassembly **300**. After inserting the fuel group subassembly **200** into the power group subassembly **300**, these two subassemblies are affixed together, e.g., by welding, such as laser welding. According to a preferred embodiment, the overmold **340** includes an opening **360** that exposes a portion of the housing **330**. This opening **360** provides access for a welding implement to weld the housing **330** with respect to the valve body **240**. Of course, other methods or affixing the subassemblies with respect to one another can be used. Finally, the O-ring **290** at either end of the fuel injector can be installed.

To ensure that particulates from the manufacturing environment will not contaminate the fuel group subassembly, the process of fabricating the fuel group subassembly is preferably performed within a "clean room." "Clean room" here means that the manufacturing environment is provided with an air filtration system that will ensure that the particulates and environmental contaminants are continually removed from the clean room.

It is believed that for cost-effectiveness in manufacturing, the number of clean room operations can constitute, inclusively, between 45–55% of the total manufacturing operations while testing processes can constitute, inclusively, between 3% and 8% of the total manufacturing operations. Likewise, the welding and screw machining operations can constitute, inclusively, between 3% and 9% of the total operations. The number operations prior to a sealed modular fuel injector unit can constitute, inclusively, between 12% and 22% of the total manufacturing processes. Of course, the operations performed prior to a sealed fuel injector unit can be done either inside or outside the clean room, depending on the actual manufacturing environment.

As an example, in a preferred embodiment, there are approximately forty-nine (49) clean room processes, seven (7) test processes, three (3) subassembly processes outside of the clean room, five (5) welding processes, one (1) machining or grinding processes, and five (5) screw machine processes that result in a sealed, or ready to be shipped, modular fuel injector unit. The total number of manufacturing operations or processes can vary depending on variables such as, for example, whether the armature assembly **260** is pre-assembled or of a one-piece construction, the lower guide and the seat being integrally formed or of separate constructions, the parts being fully finished or unfinished, the fuel or power group being provided by a third party contractor(s) or subconstractor(s), or where any portion (or portions) of the assembling processes or operations being performed by a third party assembler, either on-site or off-site, etc. These exemplary variables and other variables controlling the actual number of the predetermined number of operations, the various proportions of the clean room operations, testing, welding, screw machine, grinding, machining, surface treatment and processes outside a clean room relative to the predetermined number of operations will be known to those skilled in the art, and are within the scope of the present invention.

The method of assembly of the preferred embodiments, and the preferred embodiments themselves, are believed to provide manufacturing advantages and benefits. For example, because of the modular arrangement only the valve group subassembly is required to be assembled in a "clean" room environment. The power group subassembly **300** can be separately assembled outside such an environment, thereby reducing manufacturing costs. Also, the modularity of the subassemblies permits separate pre-assembly testing of the valve and the coil assemblies. Since only those individual subassemblies that test unacceptable are discarded, as opposed to discarding fully assembled injectors, manufacturing costs are reduced. Further, the use of universal components (e.g., the coil/bobbin unit, non-magnetic shell **230**, seat **250**, closure member **265**, filter/retainer assembly **282**' or **282**", etc.) enables inventory costs to be reduced and permits a "just-in-time" assembly of application specific injectors. Only those components that need to vary for a particular application, e.g., the terminal **320** and inlet tube **210** need to be separately stocked. Another advantage is that by locating the working air gap, i.e., between the armature assembly **260** and the pole piece **220**, within the electromagnetic coil **310**, the number of windings can be reduced. In addition to cost savings in the amount of wire **312** that is used, less energy is required to produce the required magnetic flux and less heat builds-up in the coil (this heat must be dissipated to ensure consistent operation of the injector). Yet another advantage is that the modular construction enables the orifice disk **254** to be attached at a later stage in the assembly process, even as the final step of the assembly process. This just-in-time assembly of the orifice disk **254** allows the selection of extended valve bodies depending on the operating requirement. Further advantages of the modular assembly include out-sourcing construction of the power group subassembly **300**, which does not need to occur in a clean room environment. And even if the power group subassembly **300** is not out-sourced, the cost of providing additional clean room space is reduced.

While the present invention has been disclosed with reference to certain embodiments, numerous modifications, alterations, and changes to the described embodiments are possible without departing from the sphere and scope of the present invention, as defined in the appended claims. Accordingly, it is intended that the present invention not be limited to the described embodiments, but that it have the full scope defined by the language of the following claims, and equivalents thereof.

What is claimed is:

1. A fuel injector comprising:

a housing having a passageway extending between an inlet and outlet along a longitudinal axis;

a magnetic coil cincturing a portion of the passageway;

an armature assembly being disposed along the longitudinal axis in the passageway, the armature assembly including an armature and a closure member proximate respective distal ends of the armature assembly;

a body having an inner surface exposed to the armature assembly and an outer surface surrounding the inner surface, the body extending between a first body end and a second body end so as to enclose at least a portion of the armature assembly;

a seat proximate the second body end, the seat having a seat orifice extending along the longitudinal axis between a first surface and a second surface of the seat, the seat including an outer surface contiguous to the inner surface of the body, the seat being attached to the body by at least one weld extending from an outer surface of the body to the outer surface of the seat so as to form a generally hermetic seal between the body and the seat.

2. The fuel injector of claim **1**, further comprising:

an inlet tube having a first end and a second end being coupled to the body, the second end of the inlet tube having an end portion confronting an end portion of the armature;

a filter being disposed proximate the first end of the inlet tube;

a resilient member having one portion disposed proximate the second end of the inlet tube and another portion disposed within a bore in the armature;

an adjusting tube being located within the inlet tube, the adjusting tube engaging the one portion of the resilient member so as to bias the closure member towards a position occluding flow through the seat orifice; and

a coil housing that magnetically couples the magnetic coil to the inlet tube and the body.

3. The fuel injector of claim **2**, wherein the inlet tube, filter, resilient member, adjusting tube, magnetic coil, body, armature assembly and seat are symmetrical about the longitudinal axis.

4. The fuel injector of claim **3**, wherein the closure member comprises a spheroidal member having a diameter greater than the diameter of the armature tube.

5. The fuel injector of claim **3**, wherein the pole piece and armature comprise respective end face portions generally orthogonal to the longitudinal axis and one of the end face portions having a surface oblique to the longitudinal axis, the oblique surface including a coating being formed thereon.

6. The fuel injector of claim **2**, wherein the inlet tube further comprises a first tube coupled to a pole piece.

7. The fuel injector of claim **1**, wherein the housing comprises a first housing portion enclosing a portion of the inlet and passageway and a second housing portion enclosing a portion of the outlet and passageway.

8. A fuel injector comprising:

a housing having a passageway extending between an inlet and outlet along a longitudinal axis;

a magnetic coil cincturing a portion of the passageway;

an armature assembly being disposed along the longitudinal axis in the passageway, the armature assembly including an armature and a closure member proximate respective distal ends of the armature assembly, the armature assembly comprises an armature tube extending along the longitudinal axis, the armature tube being coupled to a portion of the armature and the closure member at respective ends of the armature tube, the armature tube being provided with at least one opening generally orthogonal to the longitudinal axis and extending through the tube;

a body having an inner surface exposed to the armature assembly and an outer surface surrounding the inner surface, the body extending between a first body end and a second body end so as to enclose at least a portion of the armature assembly;

a seat proximate the second body end, the seat having a guide member contiguous to the first surface of the seat, the guide member being provided with a central through opening along the longitudinal axis and a plurality of through openings disposed about the central opening, the central through opening being adapted to guide the closure member along the longitudinal axis between an unactuated position where the closure member occludes fuel flow through the seat orifice and an actuated position where the closure member is spaced from the seat orifice so as to permit fuel flow through the seat orifice, the seat having a seat orifice extending alone the longitudinal axis between a first surface and a second surface of the seat, the seat including an outer surface contiguous to the inner surface of the body, the seat being attached to the body by at least one weld extending from an outer surface of the body to the outer surface of the seat so as to form a generally hermetic seal between the body and the seat; and

an orifice plate connected to the second surface of the seat, the orifice plate having a plurality of through openings being disposed about the longitudinal axis and in fluid communication with the passageway.

9. The fuel injector of claim **8**, wherein the armature tube comprises an inner surface telescoping over an outer surface of the portion of the armature, the inner surface of the armature tube being connected to the outer surface of the armature by at least one weld extending from the inner surface of the armature tube to the outer surface of the armature.

10. The fuel injector of claim **9**, wherein the armature tube comprises a non-magnetic tube that generally decouples a flow of magnetic flux between the armature and the closure member.

11. The fuel injector of claim **10**, wherein the armature tube comprises a deep drawn tube.

12. The fuel injector of claim **10**, wherein the armature tube comprises a rolled plate.

13. The fuel injector of claim **8**, wherein the armature tube comprises a tube having a length with respect to the longitudinal axis greater than a length of the armature with respect to the longitudinal axis.

14. The fuel injector of claim **8**, wherein the armature tube comprises an armature portion and a tubular portion, the tubular portion being connected to a closure member by at least one weld.

15. A method of forming a hermetic seal in a fuel injector, the fuel injector having a housing enclosing a passageway extending between an inlet and outlet along a longitudinal axis, and a magnetic coil disposed between the inlet and the outlet, the method comprising:

providing a body having a first body end and a second body end, the body including an outer surface and an inner surface being exposed to a seat assembly proximate the second body end, the seat assembly having a circumferential surface contiguous to the inner surface of the body and an orifice extending through the seat assembly; and

welding through the outer and inner surfaces of the body to the circumferential surface of the seat so that a hermetic lap seal is formed between the inner surface of the body and the circumferential surface of the seat assembly.

16. The method of claim **15**, wherein the welding further comprises welding an orifice plate to the second seat surface.

17. The method of claim **15**, wherein the providing comprises:

connecting a generally planar guide member to a first surface of a seat so as to form the seat assembly; and

pressing the seat assembly in the second body end to a predetermined distance in the body.

18. The method of claim **15**, wherein the providing further comprises inserting an armature assembly in the body, the armature assembly having an armature with a through-bore, an armature tube extending along the longitudinal axis, and a closure member, the armature tube being connected to a portion of the armature in a telescopic manner and being connected to the closure member at respective ends of the armature tube, the armature tube being provided with at least one opening through a side of the armature tube in fluid communication with the through bore of the armature, the at least one opening being located orthogonal to the longitudinal axis and proximate the closure member.

* * * * *